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Systems Applications, Inc., San Rafael, CA

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Volume III: Case Studies for Selected Scenarios

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16. ABSTRACT

This report describes a nine-month study to recommend and develop models that predict the contribution of man-made air pollution to visibility impairment in federal Class I areas. Two models were developed. A near-source plume model based on a Gaussian formulation was designed to compute the impact of a plume on visual range and atmospheric coloration. A regional model was designed to calculate pollutant concentrations and visibility impairment resulting from emissions from multiple sources within a region with a spatial scale of 1000 km and a temporal scale of several days. The objective of this effort was to develop models that are useful predictive tools for making policy and regulatory decisions, for evaluating the impacts of proposed new sources, and for determining the amount of emissions reduction required from existing sources, as mandated by the Clean Air Act Amendments of 1977. Volume I of this report contains the main text; Volume II contains the appendices; Volume III presents case studies of power plant plume visual impact for a variety of emission, meteorological, and ambient background scenarios.

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Volume III: Case Studies for Selected Scenarios

THE DEVELOPMENT OF MATHEMATICAL MODELS FOR THE PREDICTION OF ANTHROPOGENIC VISIBILITY IMPAIRMENT

by

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KEY TO PARAMETRIC STUDIES OF EMISSION RATES

Scattering Angle	Pasquill Stability Category	Figure	Page
45°	C	3(a)	17
	D	3(b)	18
	E	3(c)	19
90°	C	3(d)	20
	D	3(e)	21
	E	3(f)	22
180°	C	3(g)	23
	D	3(h)	24
	E	3(i)	25

Note: Base conditions are 2250 Mwe power plant, 130 km background visual range (average for western United States), 2.5 km plume-observer distance, and 0.04 ppm background ozone concentration. Each figure presents results for four emission rates.

KEY TO PARAMETRIC STUDIES OF PLUME-OBSERVER DISTANCES, SULFATE FORMATION RATES, AND BACKGROUND OZONE CONCENTRATIONS

Case				Parameter Varied							
				Plume-Observer Distance (2.5, 5, and 10 km)		Sulfate Formation Rate (0, 0.5, and 5%/hr)		Background Ozone Concentration (0, 0.04, and 0.1 ppm)		East-West Comparison	
Region	Background Visual Range (km)	Power Plant Size (Mwe)	Pasquill Stability Category	Figure	Page	Figure	Page	Figure	Page	Figure	Page
Eastern United States	15 (average)	2250	D	4(a)	29	5(a)	46	6(a)	63	7(a)	80
			E	4(b)	30	5(b)	47	6(b)	64	7(b)	81
		750	D	4(c)	31	5(c)	48	6(c)	65	7(c)	82
			D	4(d)	32	5(d)	49	6(d)	66	7(d)	83
	30 (best)	2250	D	4(e)	33	5(e)	50	6(e)	67	7(e)	84
			E	4(f)	34	5(f)	51	6(f)	68	7(f)	85
		750	D	4(g)	35	5(g)	52	6(g)	69	7(g)	86
			E	4(h)	36	5(h)	53	6(h)	70	7(h)	87
Western United States	130 (average)	2250	D	4(i)	37	5(i)	54	6(i)	71	7(a)	80
			E	4(j)	38	5(j)	55	6(j)	72	7(b)	81
		750	D	4(k)	39	5(k)	56	6(k)	73	7(c)	82
			E	4(l)	40	5(l)	57	6(l)	74	7(d)	83
	200 (best)	2250	D	4(m)	41	5(m)	58	6(m)	75	7(e)	84
			E	4(n)	42	5(n)	59	6(n)	76	7(f)	85
		750	D	4(o)	43	5(o)	60	6(o)	77	7(g)	86
			E	4(p)	44	5(p)	61	6(p)	78	7(h)	87

Note: Except as indicated otherwise on figures, the base case conditions are 5.0 km plume-observer distance, 0.5 percent/hr sulfate formation rate, 0.04 ppm background ozone concentration, and 90° scattering angle.

I INTRODUCTION

This report presents calculations of visibility impairment caused by hypothetical coal-fired power plants under different assumed emission, meteorological, and ambient background conditions. Calculations were performed using the Gaussian-based plume visibility model developed by Systems Applications, Incorporated (SAI) for the U.S. Environmental Protection Agency and described in Volumes I and II of this report. Graphs are used to illustrate the impact on calculated visibility impairment of various typical values of the following input parameters (see keys on page v):

- Emission rates.
- Atmospheric stability.
- Location of the observer relative to the power plant and the plume centerline.
- Direction of view relative to the sun (scattering angle).
- Ambient background visual range.
- Ambient background ozone concentration.
- Sulfate formation rate.

In the Clean Air Act Amendments of 1977, Congress defined visibility impairment to include a reduction in visual range and atmospheric discoloration. Four parameters that quantify visibility impairment caused by plumes have been selected for the graphs:

- Percent reduction in visual range (from background).
- Blue-red ratio (indicative of the plume coloration relative to the background, clear horizon sky).

- Plume contrast (relative to the background sky--indicative of the relative brightness of the plume).
- Plume perceptibility parameter ΔE (proportional to the plume perceptibility as a result of both brightness and color differences between the plume and the background sky).

This document is designed to offer the air quality analyst a quick reference for estimating visibility impairment caused by modern, large coal-fired power plants controlled to meet EPA's current New Source Performance Standards (NSPS) (Federal Register, 1976). These standards require efficient particulate control devices (e.g., electrostatic precipitators, baghouses, or wet scrubbers) for meeting the 20 percent opacity requirement. Meeting the current SO_2 emission standard* of 1.2 lbs/10^6 Btu requires flue gas desulfurization in the case of high-sulfur, Eastern coal, but no scrubbing for many low-sulfur, Western coals. Meeting the current 0.7 lbs/10^6 Btu NO_x emission standard requires modern boiler combustion design.

This document is limited to a few emission, meteorological, and ambient conditions that are considered typical; therefore, it is by no means meant to replace detailed model calculations or measurement programs that are carried out to identify visibility impairment. For example, these calculations would not be appropriate for estimating the impact caused by older power plants with inefficient particulate control equipment. Also, impacts during stable, light wind conditions would be much larger than those presented here, which assume a moderate wind speed of 5 m/s (11 mph). Furthermore, the impact caused by secondary aerosol--sulfates and nitrates--could be larger than those indicated here if catalytic particulates (e.g., iron, manganese) are emitted, if ambient concentrations of reactive species (e.g., $OH\cdot$, NH_3) are large, or if water droplets (e.g., from clouds, fog, or cooling tower plumes) are present.

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* More restrictive emission standards have recently been proposed.

The calculations presented here are based on certain assumptions regarding viewing conditions. It is assumed that the plume is viewed on a horizontal line of sight perpendicular to the plume centerline. If the plume were viewed down the centerline (e.g., if the observer were in an airplane or on elevated terrain), or if it were viewed obliquely, visibility impairment would be greater. Also, it is assumed that the viewing background behind the plume is the clear horizon sky. If a bright, white cloud or dark terrain feature were behind the plume, the coloration and perceptibility of the plume would change. For example, with a bright, white background, wavelength-dependent light scattering caused by aerosols contributes to the yellow-brown coloration similar to that caused by NO_2 light absorption.

Although the vertical diffusion of the plume is eventually limited to the mixed layer between the ground and the capping, stable layer, it is assumed that Pasquill-Gifford dispersion coefficients correctly describe the growth of the power plant plume at intermediate distances. There is increasing evidence that power plant plumes, due to entrainment during plume rise, are initially more dilute than are indicated by Pasquill-Gifford $\sigma_y\sigma_z$'s; and that because of their elevation, plumes diffuse less rapidly than Pasquill-Gifford $\sigma_y\sigma_z$'s indicate (Carpenter et al., 1971; Husar et al., 1978; Smith et al., 1978). Since visibility impairment is strongly dependent on the vertical thickness of the plume for horizontal lines of sight, it is essential that plume σ_z's be known as accurately as possible in order to predict visibility impairment accurately. Also, since plume $\sigma_y\sigma_z$'s at distances greater than 50 km downwind are not well known, the calculations presented here are estimates only.

Finally, the user of this document is cautioned about interpolating and extrapolating these results for different conditions. NO_2 formation in power plant plumes is diffusion-limited, that is, it is limited by the rate at which background ozone is entrained into the plume. Consequently one cannot simply substitute a ratio of these discoloration effects to correspond to light wind cases or to cases involving different emission rates.

II ASSUMED INPUT EMISSION AND AMBIENT CONDITIONS

Calculations were performed using the plume visibility model for assumed emissions from hypothetical coal-fired power plants consisting of one and three 750-Mwe units, assuming EPA's NSPS are just met. Table 1 summarizes the emission parameters.

Emission rates of fly ash, SO_2, and NO_x were computed from the NSPS emission limits of 0.1, 1.2, and 0.7 lbs/10^6 Btu, respectively; however, fly ash emissions were controlled not by the above mass emission limit, but by the 20 percent limitation on stack opacity. Emission parameters were calculated for a subbituminous B coal with a heating value of 9600 Btu/lb; if a different coal were used, emission parameters would change somewhat. It was assumed that the emitted fly ash (after particulate removal) has a mass median diameter of 1 μm, a geometric standard deviation of 2, and a density of 2 g/cm^3. On the basis of Mie calculations for this fly ash size distribution, it was found that 99.6 percent efficient particulate control equipment would be required for this particular coal to meet the NSPS 20 percent stack opacity limit.

Table 1 also shows the meteorological and ambient conditions used in the calculations. A typical (average) wind speed of 5 m/s (11 mph) at plume level and two stability categories were used: Pasquill D (neutral) and Pasquill E (slightly stable). Calculations were carried out to 250 km downwind from the source, assuming that uniform meteorological conditions persist that long (14 hours).* For Pasquill D conditions vertical mixing is eventually limited by the height of the mixed layer: 1500 m (for the eastern United States) and 2000 m (for the western United States). For cases

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* Power plant plumes have been tracked and measured as far as 300 km downwind (Husar et al., 1978; Smith et al., 1978).

TABLE 1. INPUT PARAMETERS USED IN CALCULATIONS

Parameter	Value
Coal-fired power plant emission conditions	
*Number of boilers and stacks	3, [1]
*Power output	2250, [750] Mwe
Flue gas temperature	250°F = 121°C
Flue gas flow rate per stack	1,724,000 acfm = 814 m^3/sec
Fly ash emission rate per 750-Mwe boiler	1.15 tons/day = 12.1 g/sec
Stack opacity	20%
Fly ash mass median diameter	1.0 μm
Fly ash size distribution geometric standard deviation	2.0
SO_2 emission rate per 750-Mwe unit	92.15 tons/day = 968 g/sec
*NO_x emission rate per 750-Mwe unit, as NO_2	53.75, [0] tons/day = 5.64, [0] g/sec
Meteorological and ambient conditions	
Wind speed	5.0 m/sec
*Stability category	Pasquill C, D, and E
*Background visual range	[Typical--eastern U.S.: 15 km], [Best--eastern U.S.: 30 km], Typical--western U.S.: 130 km, [Best--western U.S.: 200 km]
Background O_3 concentration	[0.0], 0.04, [0.12] ppm
*Assumed pseudo-first-order sulfate formation rate	[0], 0.5, [5] %/hr
Assumed pseudo-first-order nitrate formation rate	0 %/hr
Assumed surface deposition velocities	1 cm/sec for gases, 0.1 cm/sec for particles
*Scattering angle	[45°], 90°, [180°]
*Plume-observer distance	[2.5],† 5, [10] km

* Parameters that were varied in the sensitivity analysis.

† A plume-observer distance of 2.5 km was used as base value for Figures 2(a) through 2(i).

[ ] = Values of parameters when varied from the base value.

where vertical mixing is more severely limited, visibility impairment would be greater. Four background visual ranges were assumed in the calculations; they are representative of the typical and best eastern United States conditions (15 and 30 km) and the typical and best western, nonurban U.S. conditions (130 and 200 km). Background ozone concentrations were varied from the base case as shown in the table.

Three sulfate formation rates were assumed in the calculations, as shown. The 0.5 percent per hour rate is considered to be typical of most nonurban conditions. The 5 percent per hour value is representative of fast gas-to-particle conversion that could occur in polluted areas. Owing to the lack of quantitative data on nitrate formation in plumes, a nitrate formation rate of 0 was assumed; the validity of this assumption is uncertain. Secondary plume sulfate aerosol is assumed to be in the submicron range, with a mass median diameter of 0.18 μm, based on power plant plume measurements near St. Louis (Whitby and Sverdrup, 1978). Aerosol in this size range is most effective per unit mass in scattering light.

Several scattering angles were assumed: For the base case, a scattering angle of 90° and a solar zenith angle of 45° were used for various observer locations from 1 to 250 km downwind of the power plant and at several distances (2.5, 5, and 10 km) from the plume centerline. Figure 1 illustrates the orientations of the observer, plume, and sun that were assumed in calculations. Note that calculated visual impact refers to specific lines of sight, not to "prevailing visibility."

The effect of surface deposition on the pollutant mass flux at a given downwind distance was considered in the calculations. The surface deposition velocity was assumed to be 1 cm/sec for gases (e.g., SO_2 and NO_x) and 0.1 cm/sec for particles (e.g., fly ash and $SO_4^=$).

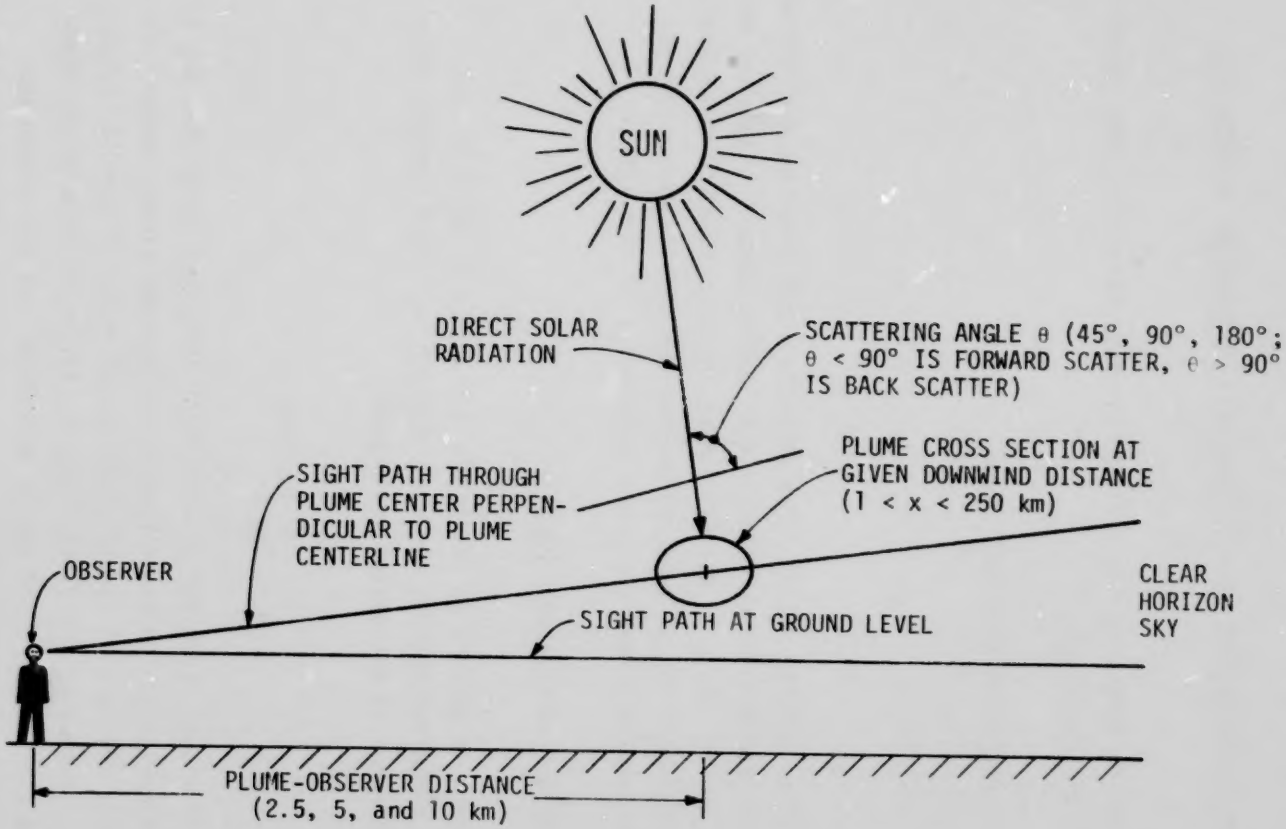

SUN
DIRECT SOLAR RADIATION
SCATTERING ANGLE θ (45°, 90°, 180°; θ < 90° IS FORWARD SCATTER, θ > 90° IS BACK SCATTER)
PLUME CROSS SECTION AT GIVEN DOWNWIND DISTANCE (1 < x < 250 km)
SIGHT PATH THROUGH PLUME CENTER PERPEN-DICULAR TO PLUME CENTERLINE
OBSERVER
CLEAR HORIZON SKY
SIGHT PATH AT GROUND LEVEL
PLUME-OBSERVER DISTANCE (2.5, 5, and 10 km)

FIGURE 1. GEOMETRY OF PLUME, OBSERVER, AND SUN ASSUMED IN CALCULATIONS

III INTERPRETATION OF VISIBILITY IMPAIRMENT PARAMETERS

Each of the accompanying figures displays four parameters that characterize visibility impairment:

- Percent reduction in visual range
- Blue-red ratio
- Plume contrast
- ΔE.

In this section we briefly define these parameters and describe what typical values for them mean using the following qualitative terms: bright and dark; yellow, brown, white, and grey discoloration; imperceptible and perceptible. More detailed explanations of these parameters and details concerning the models used to calculate them are given in Volume I of this report.

A. PERCENT REDUCTION IN VISUAL RANGE

Visual range is defined as the farthest distance at which a black object can be perceived against the clear horizon sky. The percent reduction in visual range is calculated as follows:

$$\left(1 - \frac{r_v}{r_{v0}}\right) \times 100\% \quad ,$$

where r_v is the visual range for views through the plume center and r_{v0} is the visual range without the plume (ambient background visual range). In most situations, the percent reduction in visual range is directly proportional to the integral of the plume light scattering and absorption coefficients along the line of sight and is independent of the background visual range. The percent reduction in visual range is indicative of the "haziness" of objects observed through the plume. Until it is diffused,

the plume will affect only a few of the observer's lines of sight; therefore, calculated visual range reduction pertains only to specific lines of sight through the plume center (perpendicular to the plume centerline), not to prevailing visibility. The magnitude of visual range reduction is not necessarily related to the perceptibility of the plume or to atmospheric discoloration. A significant reduction in visual range could occur without a perceptible plume or atmospheric discoloration. This occurrence is illustrated in our subsequent discussion of plume impact under typical ambient conditions for the eastern United States.

B. BLUE-RED RATIO

The blue-red ratio indicates the coloration of the plume relative to the unaffected background sky. It is the ratio of the plume light intensity at the blue end of the visible spectrum (λ = 0.4 μm) to that at the red end (λ = 0.7 μm) divided by the same ratio for the background:

$$R = \frac{I_{plume}(blue)/I_{back}(blue)}{I_{plume}(red)/I_{back}(red)} \quad .$$

A ratio of 1 indicates that the plume is the same color as the background sky, though not necessarily of the same brightness. Ratios greater than 1 indicate bluish discoloration relative to the background, and ratios of less than 1 indicate yellowish discoloration. If the background sky is blue, the plume could be white or grey with a ratio of less than 1 because the ratio is a relative discoloration index. The plume color will be a more saturated yellow with decreasing values of this ratio (<0.9).

C. PLUME CONTRAST

Plume contrast is the normalized difference in light intensity of the plume relative to the background:

$$C_p = \frac{I_p(0.55\ \mu m) - I_b(0.55\ \mu m)}{I_b(0.55\ \mu m)} \quad .$$

Contrast is evaluated at a wavelength λ of 0.55 μm, which is the midpoint of the visible spectrum where the human eye is most sensitive. With no color shifts (that is, with a blue-red ratio = 1), a plume will be visible only if it is sufficiently brighter ($C_p > 0$) or darker ($C_p < 0$) than the background sky. There are no experimental data concerning the perceptibility threshold contrast for plumes. A threshold contrast of 0.02 is used in defining the perceptibility of a dark object against the horizon sky in the calculation of visual range; however, it is likely that the threshold contrast for plumes is greater than 0.02 because, in many cases, the boundary between a plume and the background is not distinct owing to the nature of plume dilution. The use of the blue-red ratio in conjunction with the plume contrast at 0.55 μm is a simple way of characterizing plume color. When $R > 1$, the plume is more blue than the background; when $R < 1$, the plume is redder (or more yellow-brown); when $R = 1$, with $C_p(0.55\ \mu m) > 0$, the plume is a brighter white than the horizon, and with $C_p(0.55\ \mu m) < 0$, the plume is a darker grey.

D. PLUME PERCEPTIBILITY PARAMETER ΔE

The final step in the quantification of plume perceptibility is the specification of color differences--differences both in color and brightness. In 1976 the Commission Internationale de l'Eclairage (CIE) adopted two color difference formulae by which the perceived magnitude of color differences can be calculated. Color differences are specified by a parameter ΔE, which is a function of the change in light intensity or value (ΔL*) and the change in chromaticity (Δx,Δy). ΔE can be considered as a distance between two colors in a color space that is transformed in

such a way that equal distances (ΔE) between any two colors correspond to equally perceived color changes. This suggests that a threshold (ΔE_0) can be found to determine whether a given color change is perceptible.

Since the CIE could not decide between two different proposed formulae for ΔE, both were adopted in 1976 as standard means by which color differences can be specified. These color differences, which are labeled $\Delta E(L^*U^*V^*)$ and $\Delta E(L^*a^*b^*)$, are calculated by the plume visibility code. We have elected to plot $\Delta E(L^*a^*b^*)$. A ΔE of greater than 20 indicates a strong discoloration, ΔE's between 5 and 20 represent weak discoloration, and with a ΔE lsss than 5, a plume would probably not be perceptible. It is currently uncertain as to what the thresholds of perceptibility are in terms of values of blue-red ratio, plume contrast, and ΔE.

E. SUMMARY

Figure 2 summarizes these qualitative interpretations of the quantitative specifications of visibility impairment and may be used as a key to Figures 3 through 7.

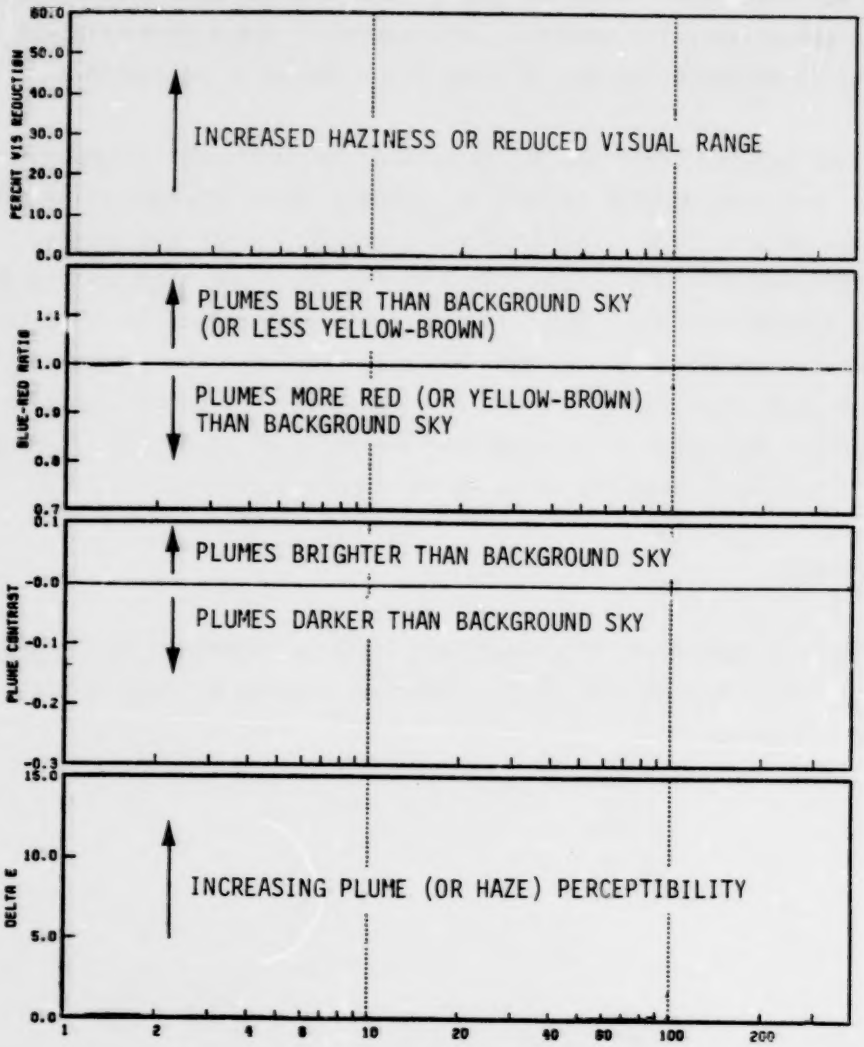


FIGURE 2. KEY TO PARAMETERS USED TO CHARACTERIZE VISIBILITY IMPAIRMENT

IV EFFECTS OF EMISSIONS, ATMOSPHERIC STABILITY, AND SCATTERING ANGLE ON PLUME VISIBILITY IMPAIRMENT

Figures 3(a) through 3(i), presented at the end of this chapter, illustrate calculated plume visibility impairment resulting from the hypothetical, three-unit, 2250-Mwe, coal-fired power plant. For all of these plots, the background ambient conditions are typical of those in nonurban areas of the western United States: The background visual range is 130 km, and the background ozone concentration is 0.04 ppm. The observer is assumed to be situated 2.5 km from the plume centerline, at the indicated downwind distances. See the key on page v and Table 1 for base conditions.

Four emission/formation scenarios are assumed and illustrated in each of these figures:

(1) Normal NO_x emissions (at the NSPS limit); 0.5 %/hr sulfate formation (the base case).
(2) Normal NO_x emissions; no sulfate formation (equivalent to the assumption of no SO_2 emissions, or complete flue gas desulfurization).
(3) No NO_x emissions; 0.5 %/hr sulfate formation (equivalent to complete NO_x removal and no SO_2 removal).
(4) No NO_x emissions; no sulfate formation (equivalent to complete NO_x and SO_2 control except for fly ash emissions).

Figures 3(a), 3(b), and 3(c) illustrate for a scattering angle of 45° (a forward scattering case--sun in front of observer) the visibility impairment parameters for Pasquill stabilities C, D, and E, respectively. Figures

3(d), 3(e), and 3(f) show the same plots for a scattering angle of 90°; and Figures 3(g), 3(h), and 3(i) show the impact for a scattering angle of 180° (a backscatter case--sun behind the observer).

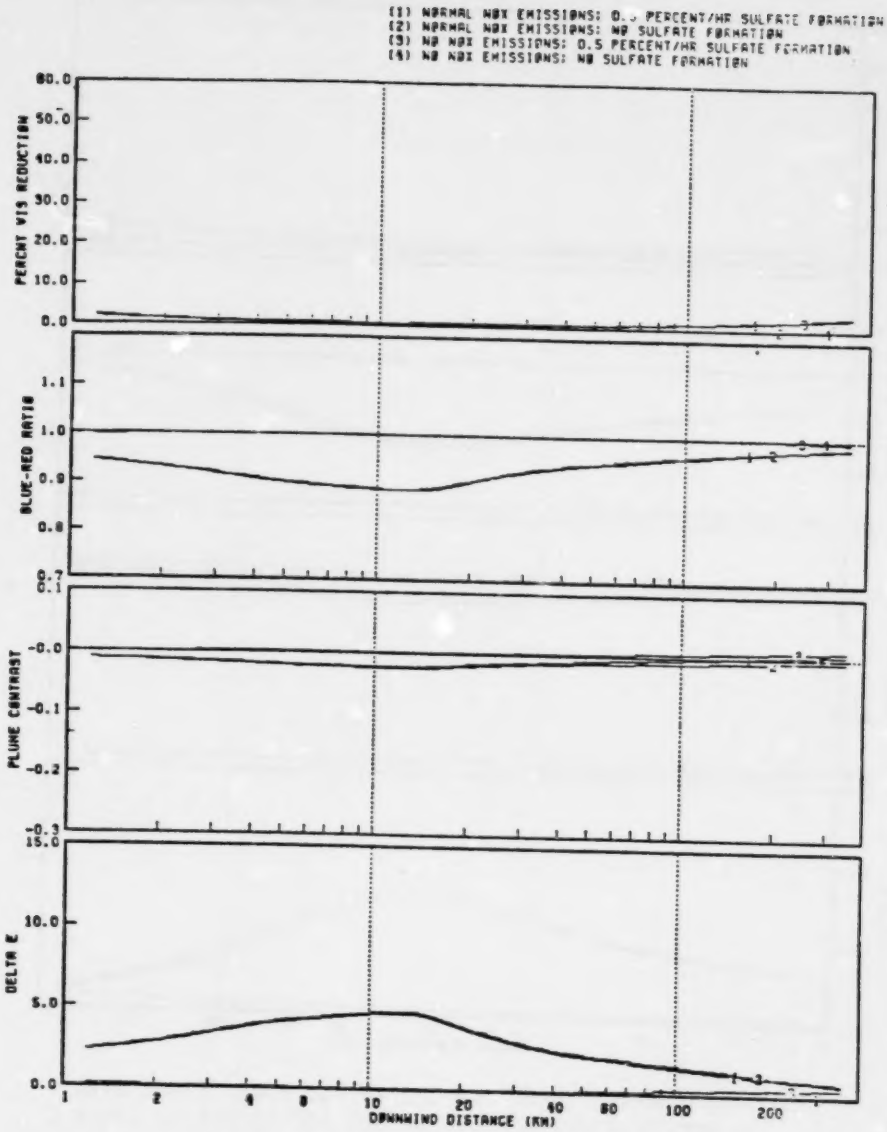
By comparing these nine figures, the following observations can be made:

- Plume visibility impairment is greatest during stable atmospheric conditions (Pasquill E). More stable conditions or lighter winds (allowing less dispersion) would result in still greater visibility impairment.
- The effect of the orientation of the sun relative to the observer and plume (scattering angle) is chiefly manifested in the relative brightness of the plume, as indicated by plume contrast. In backscatter, the plume is always darker than the background; in forward scatter, when NO_x is not emitted, the plume is always brighter than the background: In such a situation, more light is scattered toward the observer when the sun is in front of the observer ($\Theta < 90°$) than when the sun is behind the observer ($\Theta > 90°$).
- The impact of fly ash on visual range (see Case No. 4 in these figures) is negligible, but is greatest (a 5 percent reduction) during stable conditions, 1 km downwind (the closest distance considered).
- The impact on visual range of sulfate formed in the atmosphere from SO_2 emissions (see Case No. 3 in these figures) is small, but increases with distance downwind and with increasing stability, reaching a maximum of about a 10 percent reduction for stable conditions (Pasquill E) at the farthest distance considered (350 km).
- The impact of NO_2 on visual range is negligible for the plume-observer distance assumed in these calculations

(2.5 km). (This impact on visual range increases with increasing plume-observer distance, as will be shown in subsequent plots.)

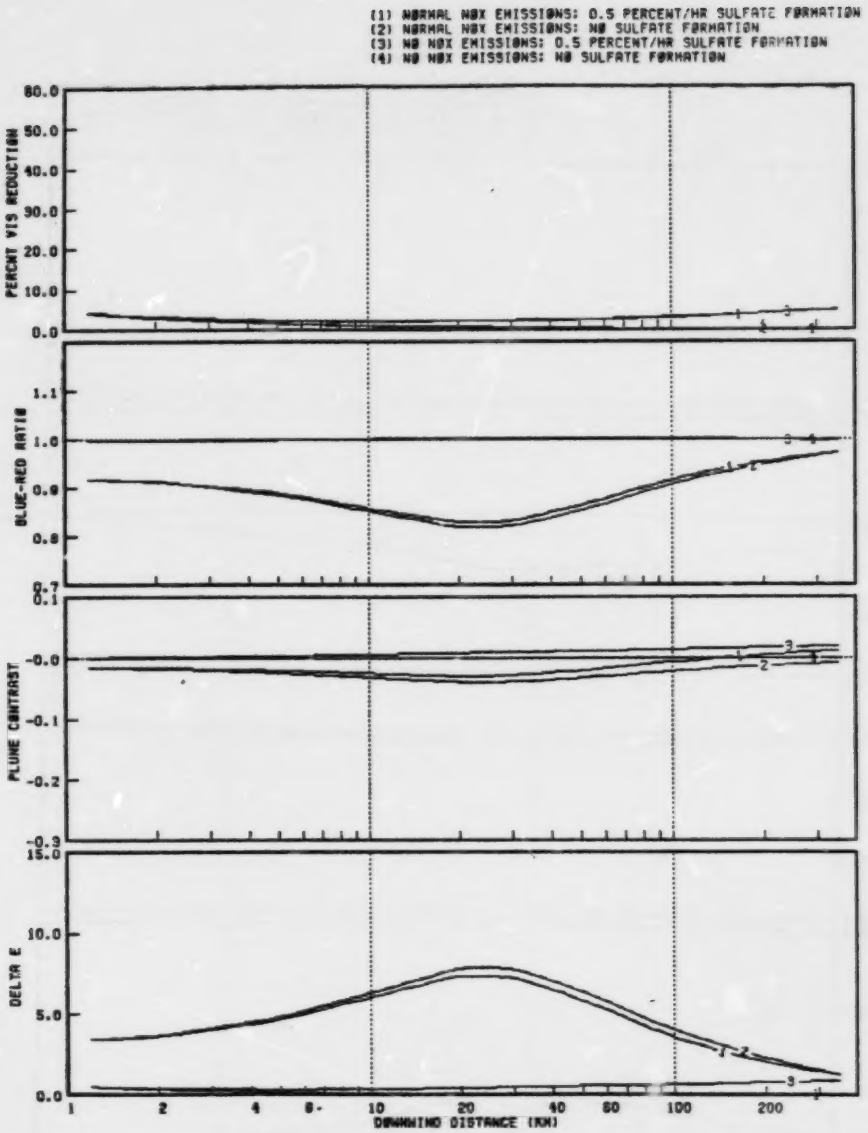
- Sulfate aerosol and fly ash (Case Nos. 3 and 4) have almost no effect on discoloration, as indicated by the blue-red ratio. However, it should be noted that sulfate plumes (Case No. 3) are brighter (whiter) in forward scatter and darker (greyer) in backscatter than the background sky.
- NO_2 formed in the plume has the most significant effect on plume coloration and plume perceptibility, as indicated by the blue-red ratio and ΔE. NO_2 is the dominant colorant, though sulfate contributes slightly, in backscatter situations.
- For all scattering angles, sulfate aerosol will reduce somewhat the NO_2 coloration, as evidenced by blue-red ratio, because of the masking effect of scattered light; however, in backscatter only ($\theta = 180°$), sulfate contributes to plume perceptibility, as evidenced by larger ΔE values, because of its darkening effect (negative plume contrasts).
- The location downwind from the power plant, at which the maximum discoloration occurs and at which the plume is most perceptible, varies with the rate of plume dilution. During well-mixed conditions [Pasquill C--see Figures 2(a), 2(d), and 2(g)], a plume would be most colored (blue-red ratio < 0.9) and most likely to be visible ($\Delta E > 5$) at 10 to 15 km downwind. However, since $\Delta E = 5$, the plume would probably not be noticeable. During neutral conditions [Pasquill D--see Figures 2(b), 2(e), and 2(h)], maximum plume coloration and perceptibility occurs at about 25 km downwind. The blue-red ratio of about 0.82 and the ΔE value of 7 indicate that, at this distance, the plume would appear slightly yellowish; however,

some people might not notice the plume at all. For stable conditions [Pasquill E--see Figures 2(c), 2(f), and 2(i)], the maximum discoloration (blue-red ratio = 0.78) occurs at 40 km downwind and the plume would be perceptible (ΔE = 10) to most people as a grey-yellow haze. Decreasing plume coloration at distances beyond the maximum results from plume dilution.



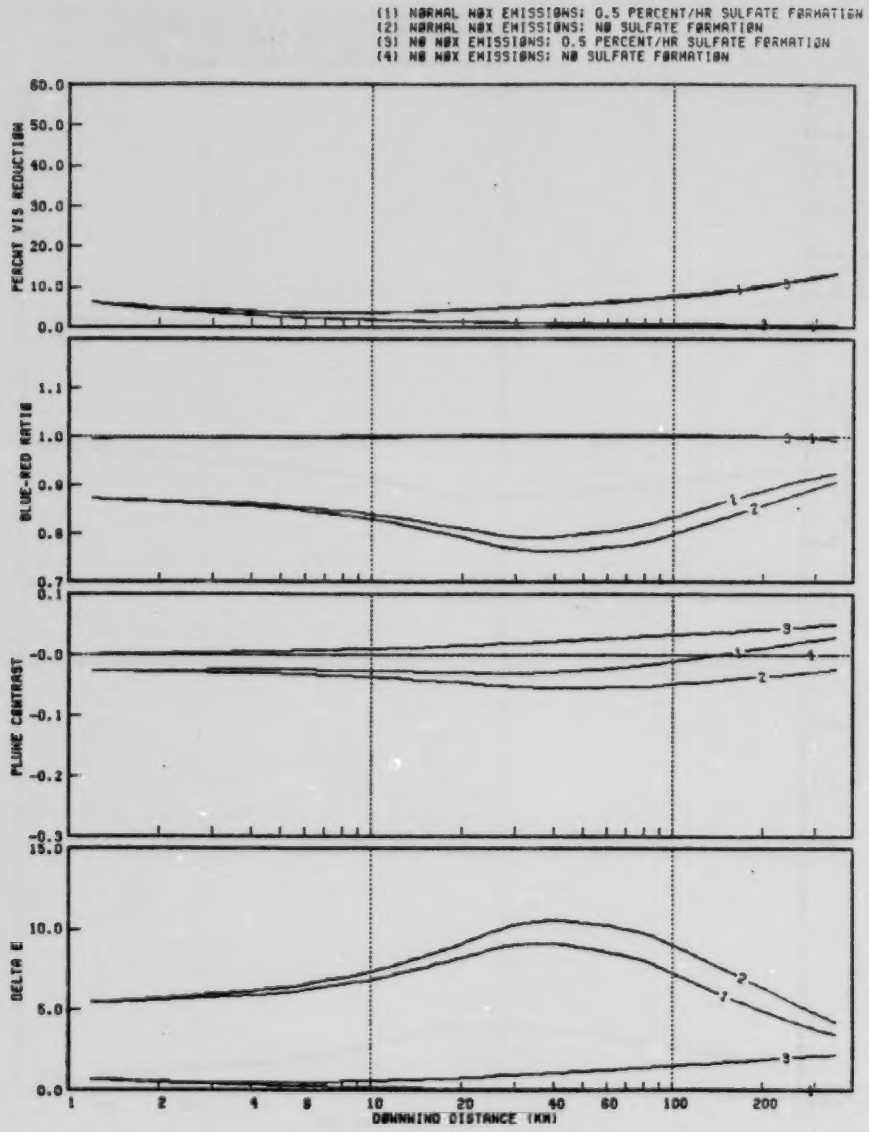
(a) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 45° and Stability Class C

FIGURE 3. CALCULATED PLUME VISIBILITY IMPAIRMENT


(1) NORMAL NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(2) NORMAL NOX EMISSIONS: NO SULFATE FORMATION
(3) NO NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS: NO SULFATE FORMATION
PERCENT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

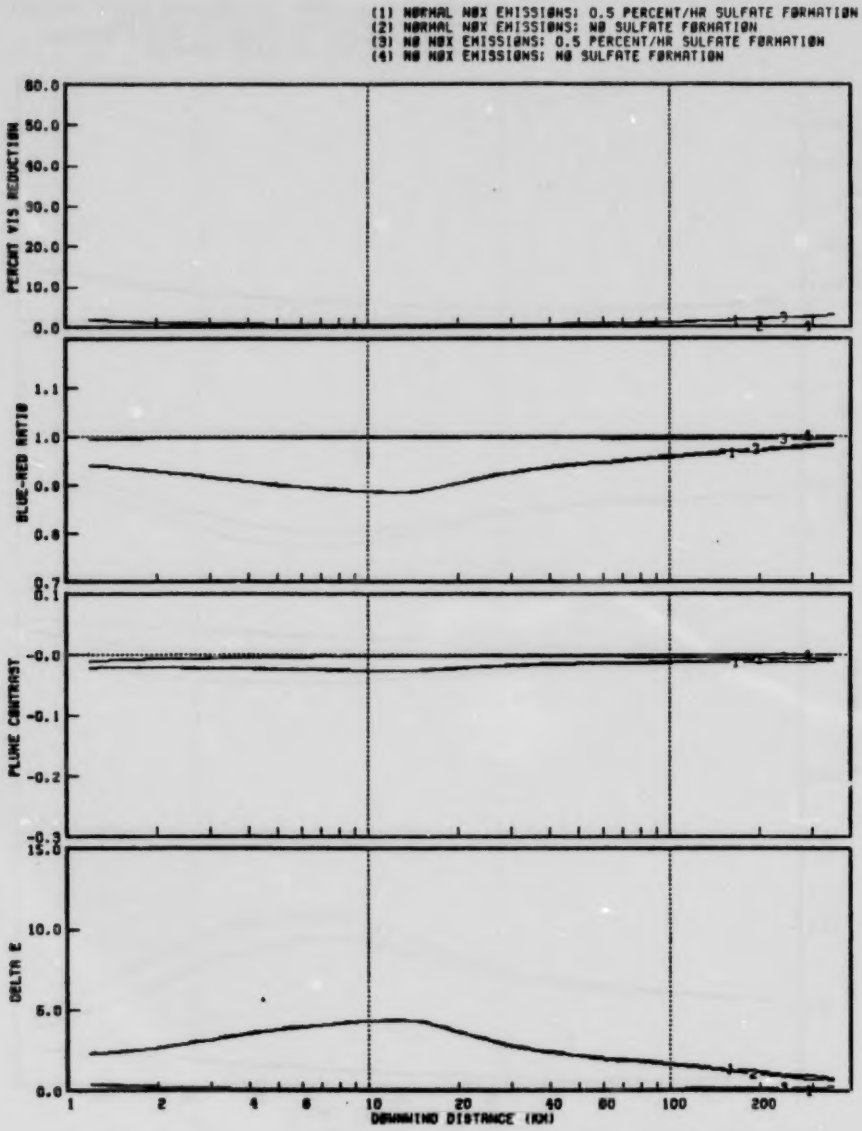
(b) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 45° and Stability Class D

FIGURE 3 (Continued)


(1) NORMAL NOX EMISSIONS; 0.5 PERCENT/HR SULFATE FORMATION
(2) NORMAL NOX EMISSIONS; NO SULFATE FORMATION
(3) NO NOX EMISSIONS; 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS; NO SULFATE FORMATION
PERCNT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

(c) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 45° and Stability Class E

FIGURE 3 (Continued)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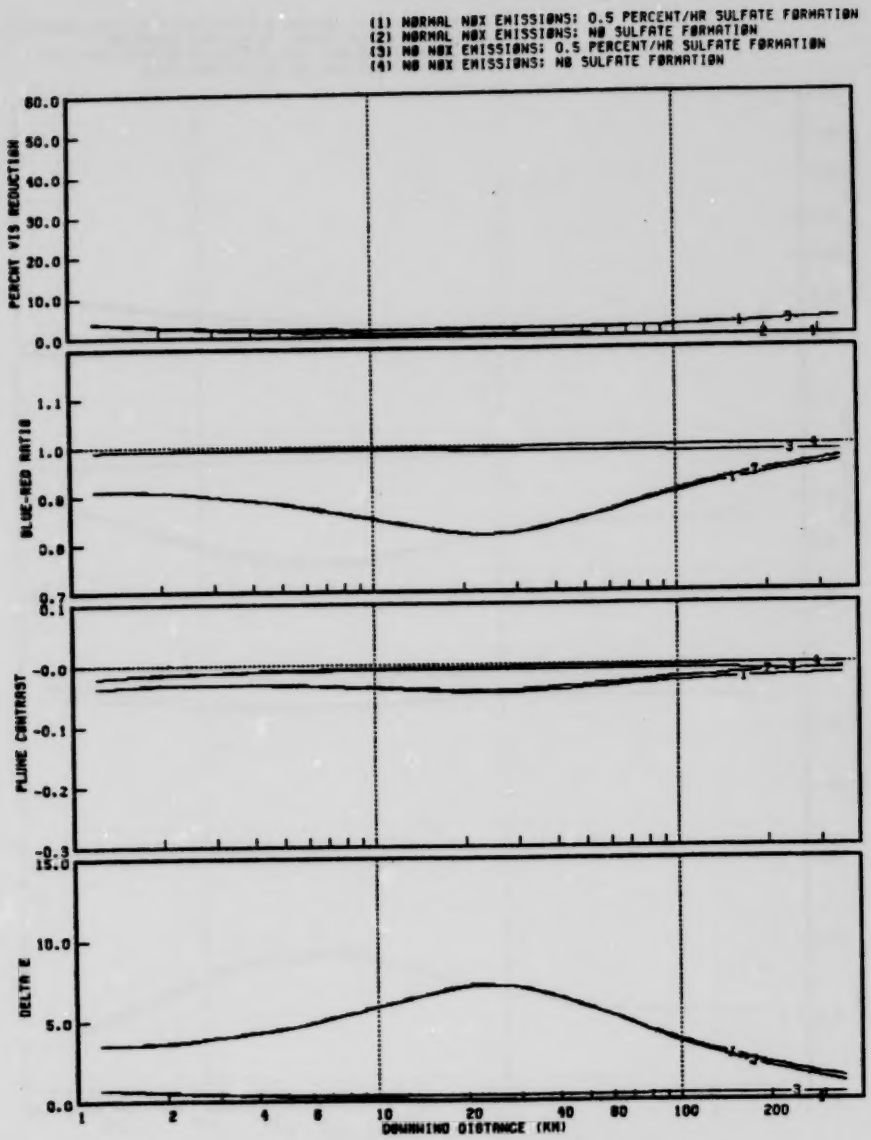
(2) NORMAL NOX EMISSIONS: NO SULFATE FORMATION
(3) NO NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS: NO SULFATE FORMATION
PERCENT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

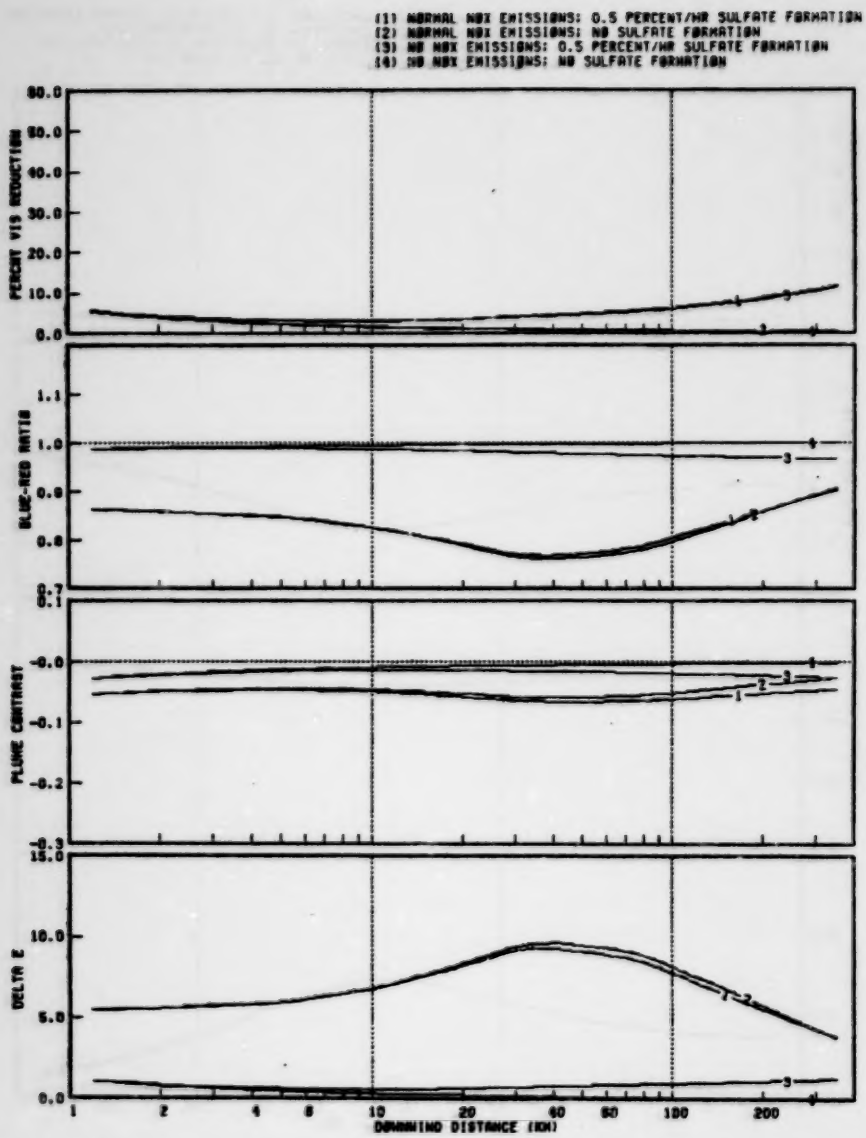
(d) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 90° and Stability Class C

FIGURE 3 (Continued)


(1) NORMAL NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(2) NORMAL NOX EMISSIONS: NO SULFATE FORMATION
(3) NO NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS: NO SULFATE FORMATION
PERCENT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

(e) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 90° and Stability Class D

FIGURE 3 (Continued)


(1) NORMAL NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
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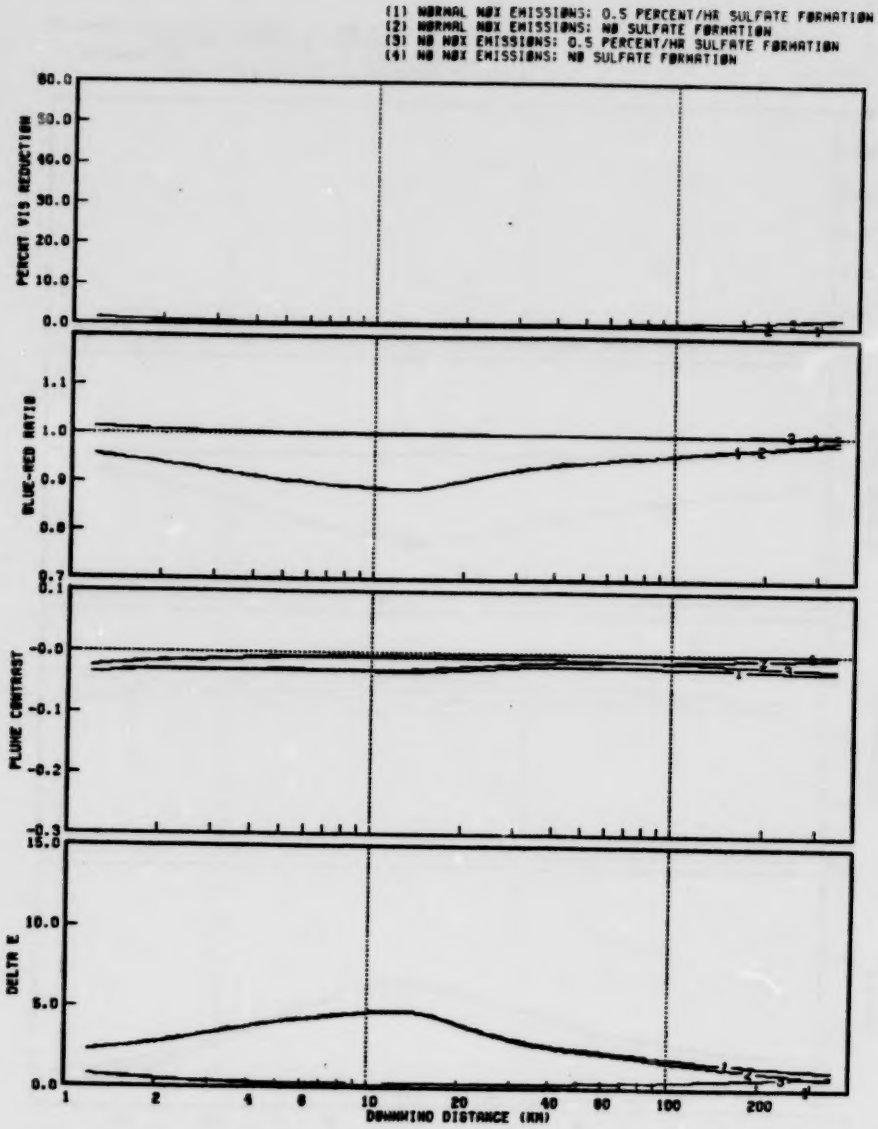
(3) NO NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS: NO SULFATE FORMATION
PERCENT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

(f) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 90° and Stability Class E

FIGURE 3 (Continued)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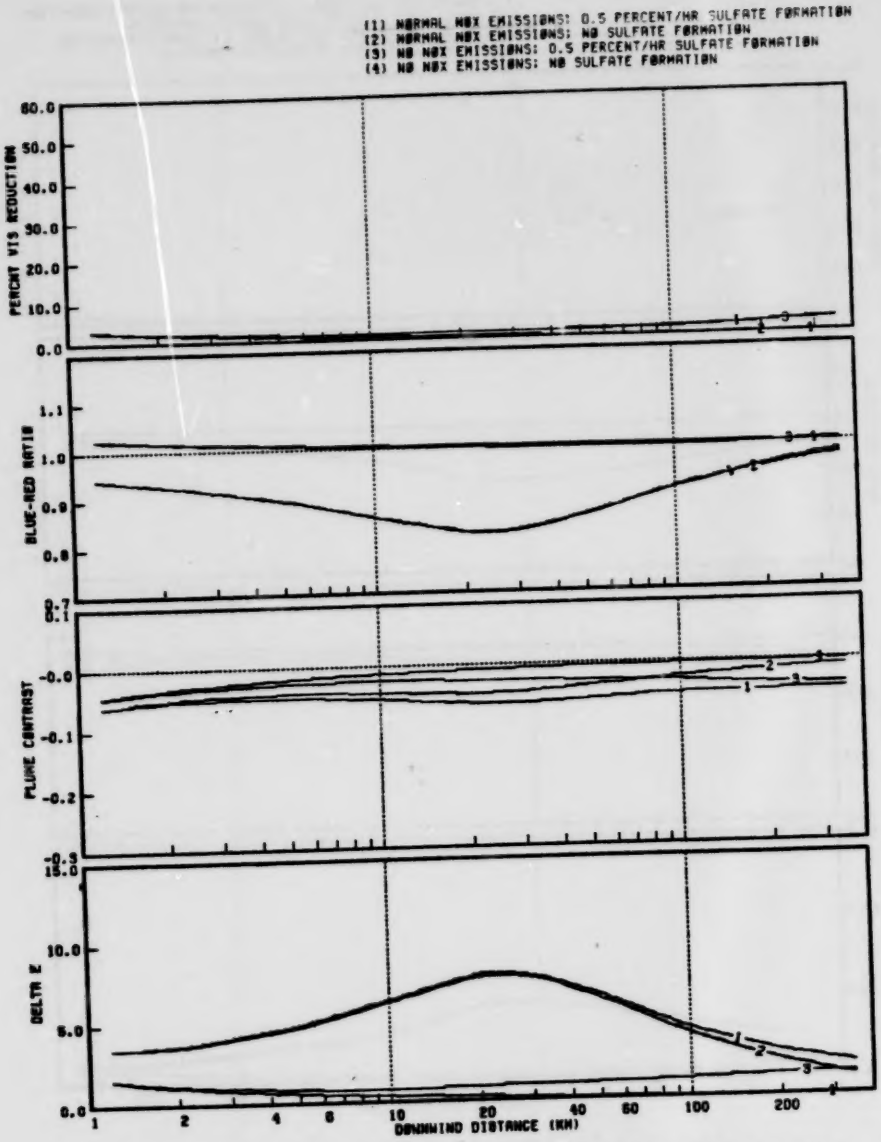
(2) NORMAL NOX EMISSIONS: NO SULFATE FORMATION
(3) NO NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS: NO SULFATE FORMATION
PERCENT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

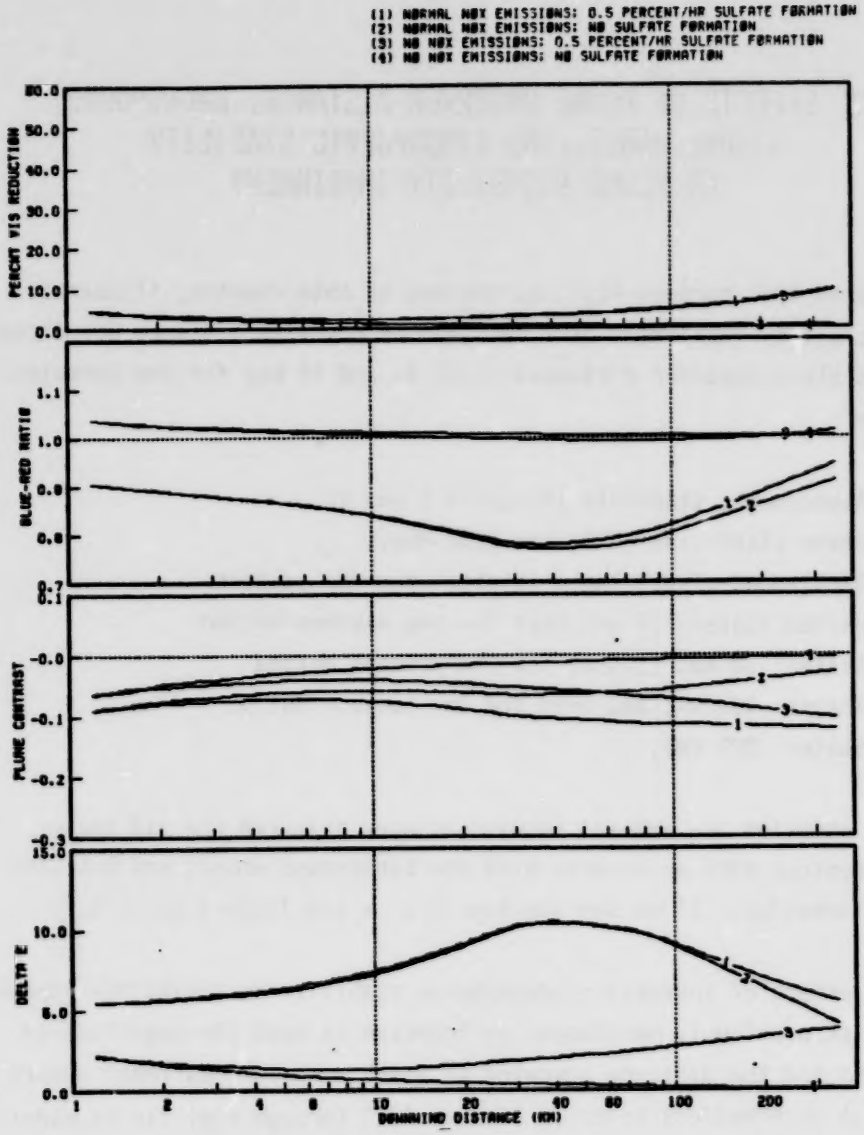
(g) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 180° and Stability Class C

FIGURE 3 (Continued)


(1) NORMAL NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(2) NORMAL NOX EMISSIONS: NO SULFATE FORMATION
(3) NO NOX EMISSIONS: 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS: NO SULFATE FORMATION
PERCENT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

(h) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 180° and Stability Class D

FIGURE 3 (Continued)


(1) NORMAL NOX EMISSIONS; 0.5 PERCENT/HR SULFATE FORMATION
(2) NORMAL NOX EMISSIONS; NO SULFATE FORMATION
(3) NO NOX EMISSIONS; 0.5 PERCENT/HR SULFATE FORMATION
(4) NO NOX EMISSIONS; NO SULFATE FORMATION
PERCENT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

(i) Hypothetical 2250-Mwe Coal-Fired Power Plant with Light Scattering Angle of 180° and Stability Class E

FIGURE 3 (Concluded)

V EFFECTS OF PLUME OBSERVER DISTANCE, BACKGROUND VISUAL RANGE, AND ATMOSPHERIC STABILITY ON PLUME VISIBILITY IMPAIRMENT

Figures 4(a) through 4(p), at the end of this chapter, illustrate plume visibility impairment as a function of downwind distance for three different plume-observer distances (2.5, 5, and 10 km) for the permutations of:

- Atmospheric stability (Pasquill D and E).
- Power plant size (750- and 2250-Mwe).
- Background visual range (typical for the eastern United States: 15 km; best for the eastern United States: 30 km; typical for the western United States: 130 km; and best for the western United States: 200 km).

The base emission and ambient conditions were selected for all these cases: typical NSPS emissions; 0.04 ppm background ozone; and 0.5 %/hr sulfate formation. (Also see the key on p. v and Table 1 on p. 5.)

The effect of increasing atmospheric stability on visibility impairment is, as previously mentioned, an increase in both the magnitude of impairment and the distance downwind at which maximum impairment occurs. Additional observations based on Figures 4(a) through 4(p) can be made:

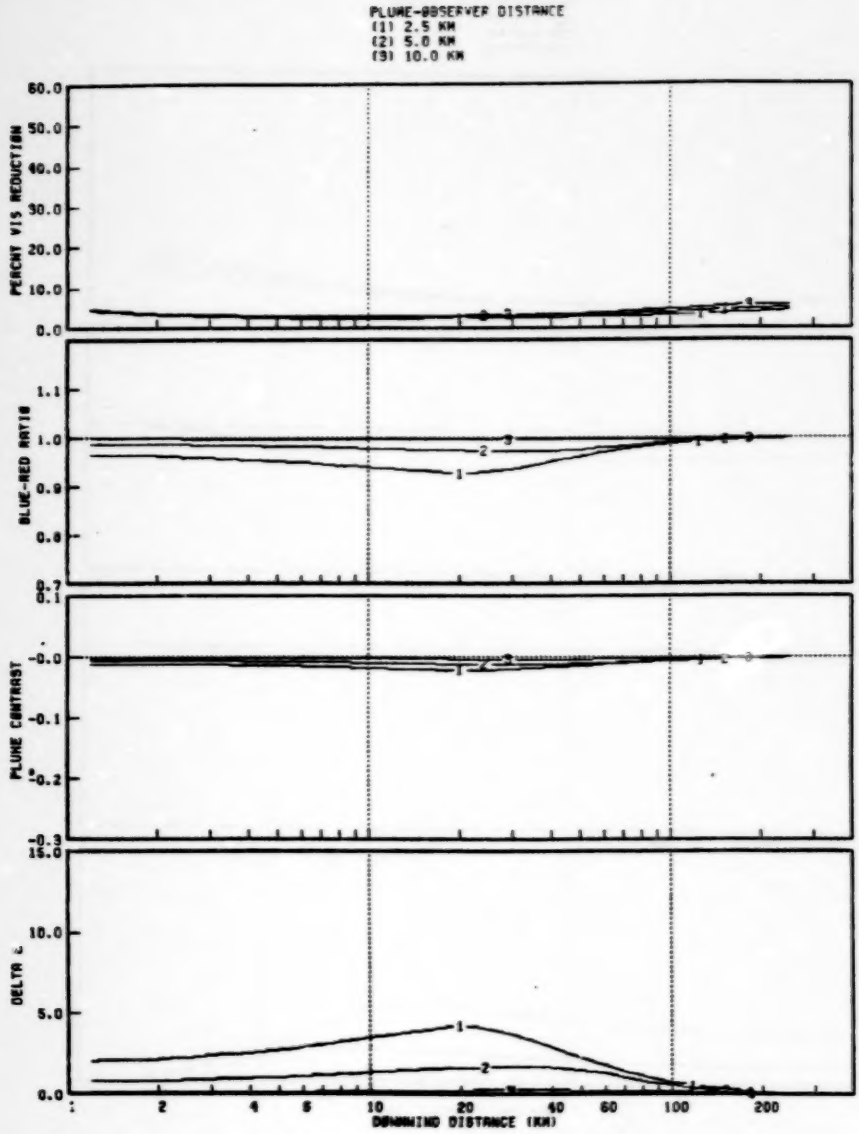
- For given emissions and stability, the percent reduction in visual range is not affected by the magnitude of the background visual range.
- The percent reduction in visual range increases with increasing plume-observer distance for two reasons. First, as the plume diffuses, some of the plume material

diffuses beyond the observer at a fixed distance from the plume centerline and is not within the given line of sight. Second, plume NO_2 will have a greater effect on visual range when plume discoloration is reduced owing to plume dispersion.

- Since visual range reduction is proportional to plume sulfate flux, and since SO_2-to-$SO_4^=$ conversion is assumed to be first-order, the impact on visual range of the three-unit (2250-Mwe) plant is three times the impact of the single-unit (750-Mwe) plant.
- As the background visual range decreases and plume-observer distance increases, the discoloration of the plume becomes less pronounced because of the masking effect of light scattered by the background aerosol. For typical eastern United States conditions [see, for example, Figure 4(b)], a plume would not be visible at all since $\Delta E < 5$; for typical western United States conditions [see, for example, Figure 4(j)], a plume might be faintly visible as a yellow haze ($5 < \Delta E < 10$); however, coloration decreases with increasing plume-observer distance.
- The location downwind from the power plant at which maximum discoloration occurs increases with increasing stability and increasing plume-observer distance.
- Plume perceptibility and coloration is more severe in areas such as the nonurban western United States, where the background visual range is excellent. For the conditions investigated, plumes in the eastern United States would not be perceptible.
- Unlike visual range, plume discoloration and perceptibility is not proportional to power plant emissions or size because NO-to-NO_2 conversion is not linear and is diffusion-limited. For example, Figure 4(n) indicates a maximum plume perceptibility ΔE value of 10 for the 2250-Mwe plant, while Figure 4(p)

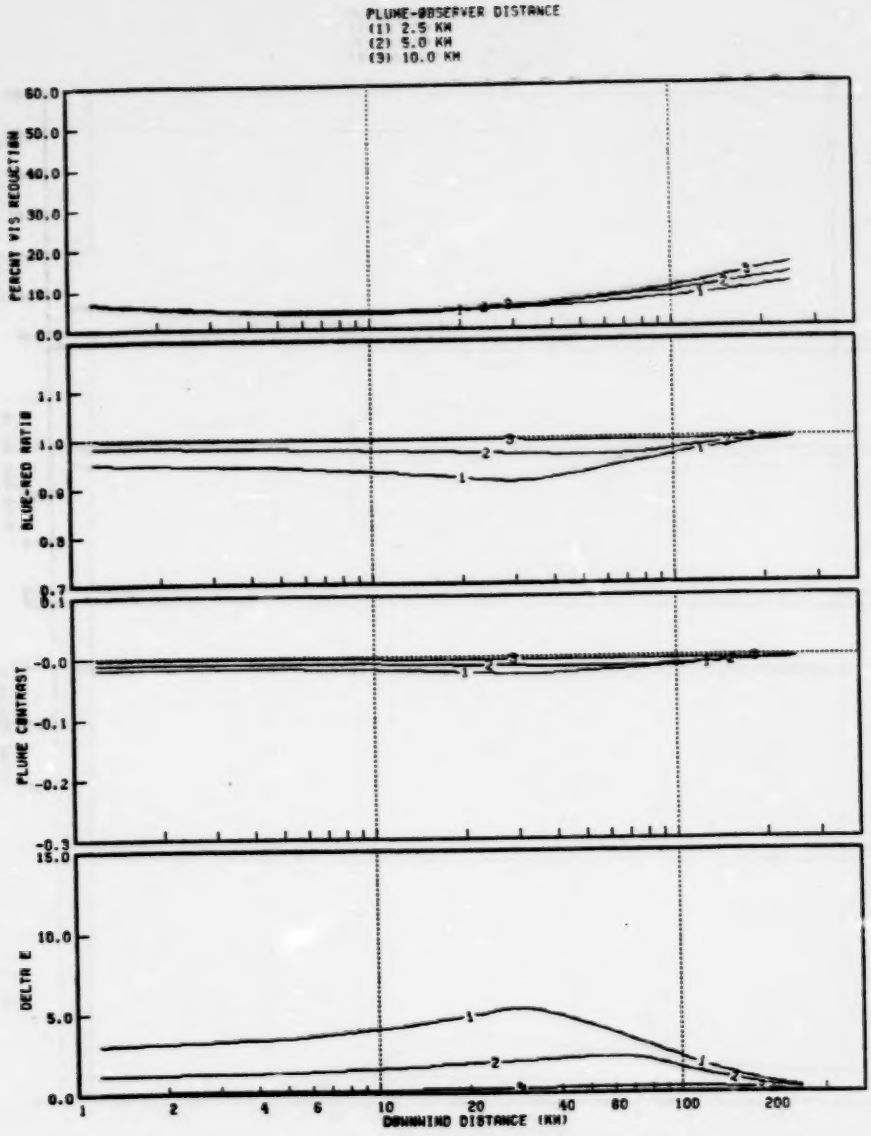
indicates that, under identical ambient conditions, the maximum coloration impact of a 750-Mwe plant corresponds to a ΔE of 5, more than one-third the impact of the three-unit plant. .

- Discoloration and plume perceptibility would increase if a light wind situation ($u < 2$ m/sec) occurred, or if the plume were viewed along the plume axis or obliquely instead of with the line of sight perpendicular to the plume axis, as was assumed in these calculations.



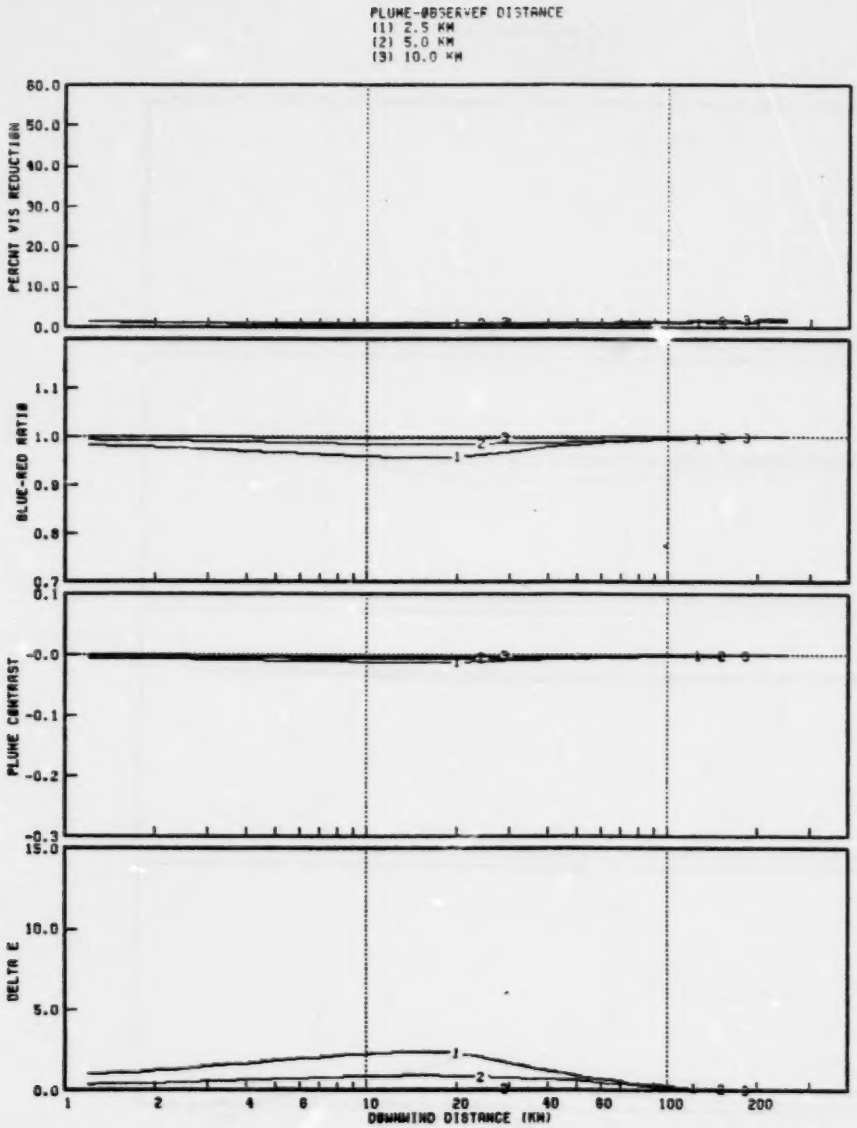
(a) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability D

FIGURE 4. EFFECT OF PLUME-OBSERVER DISTANCE ON CALCULATED VISIBILITY IMPAIRMENT



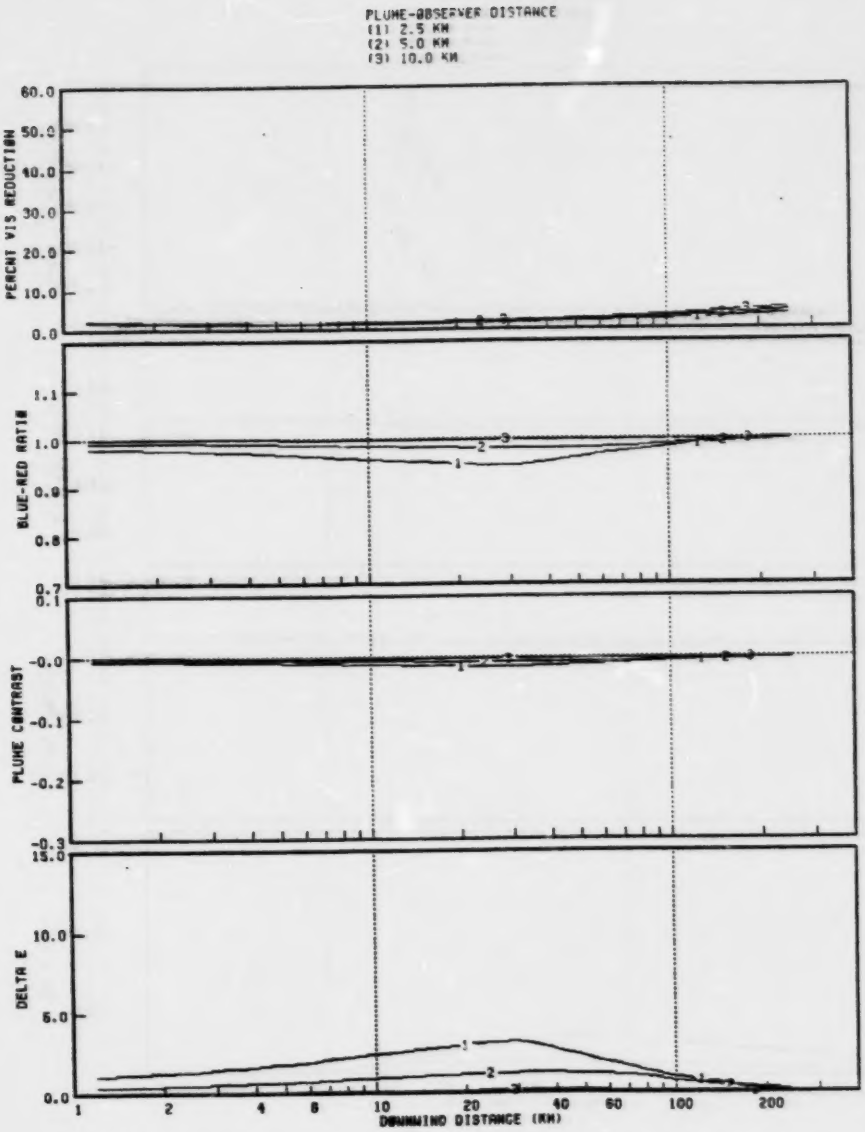
(b) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability E

FIGURE 4 (Continued)



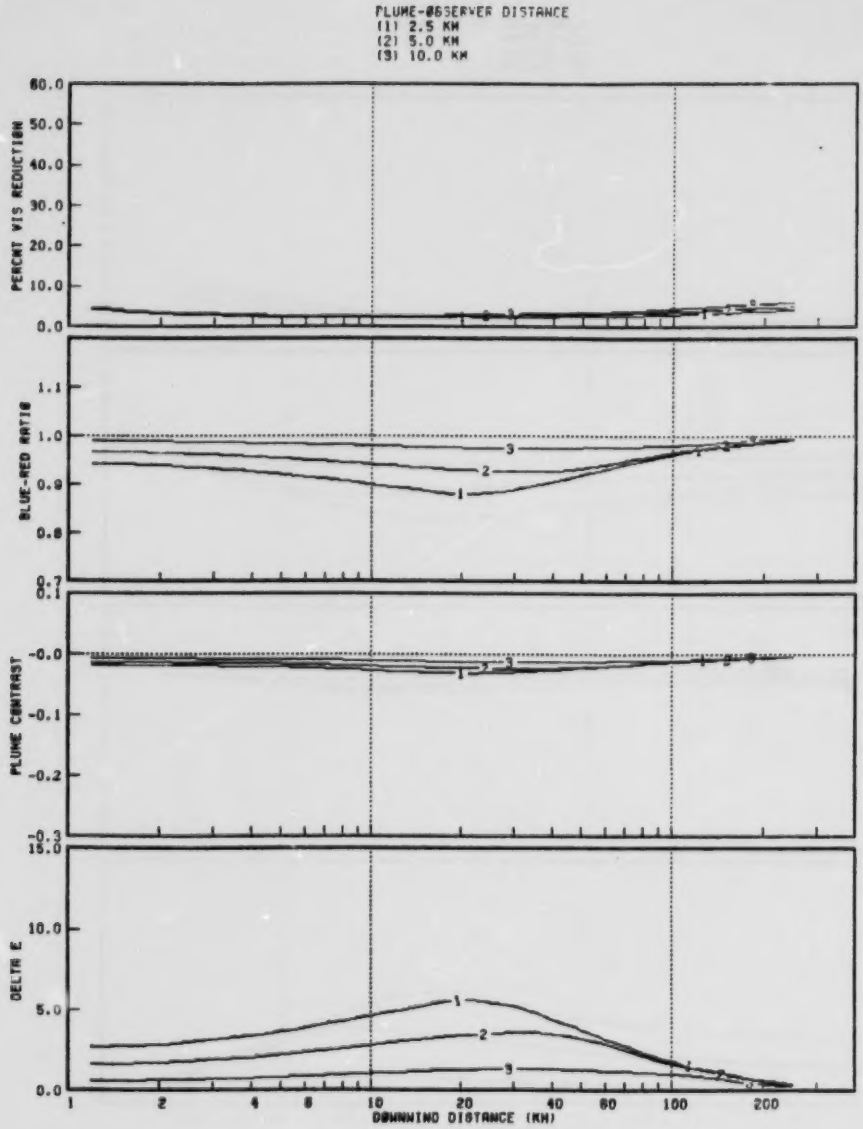
(c) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability D

FIGURE 4 (Continued)



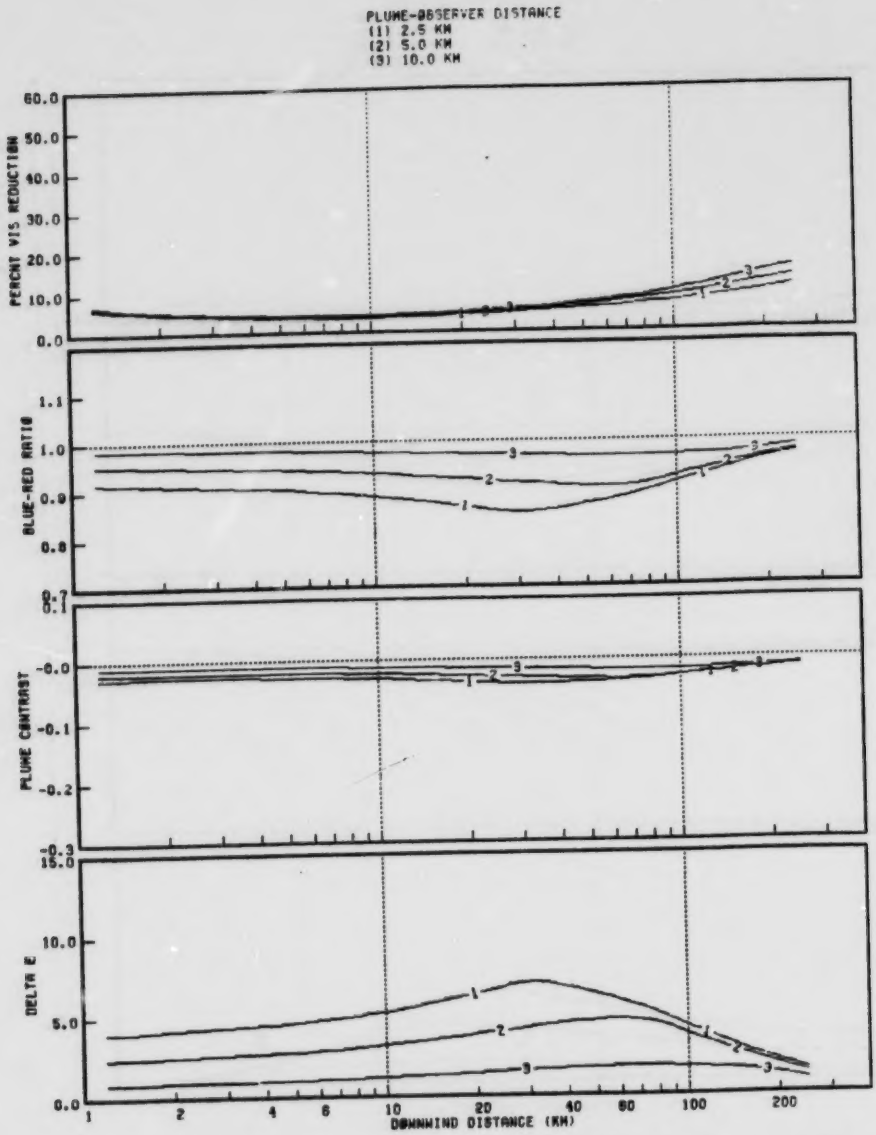
(d) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability E

FIGURE 4 (Continued)



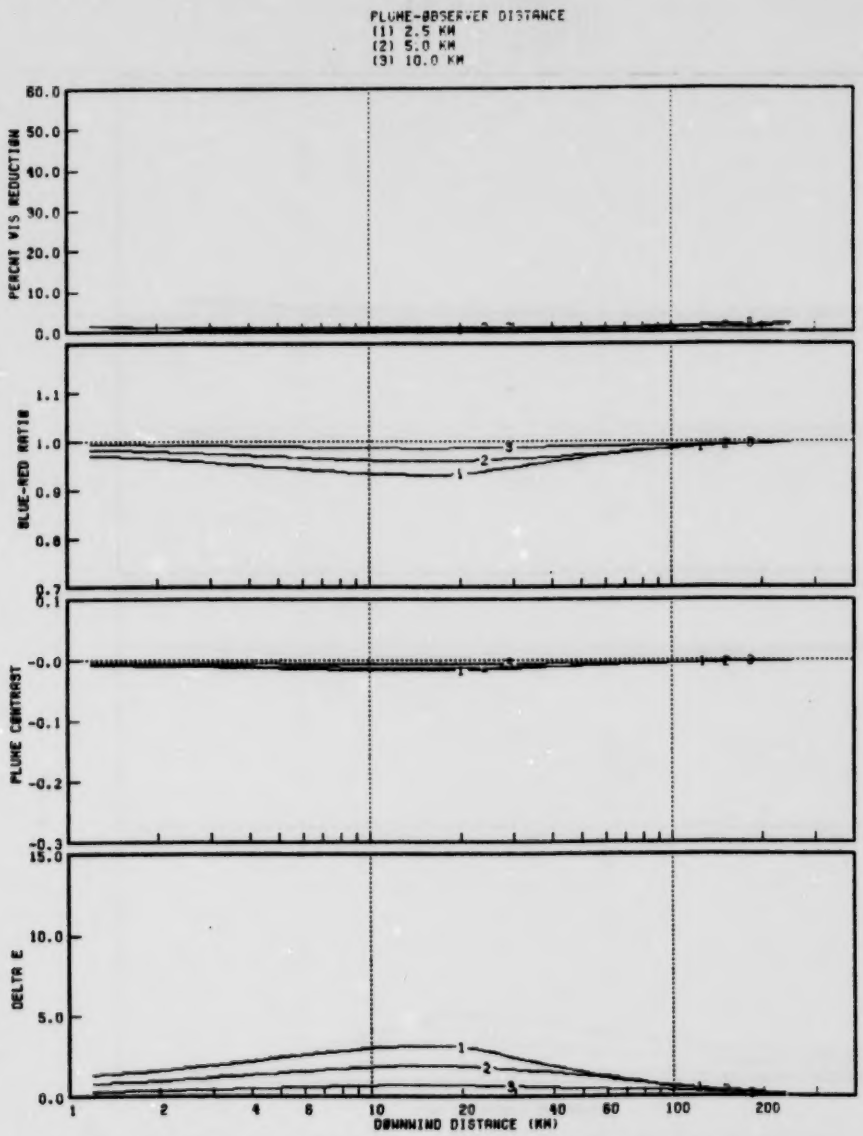
(e) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability D

FIGURE 4 (Continued)



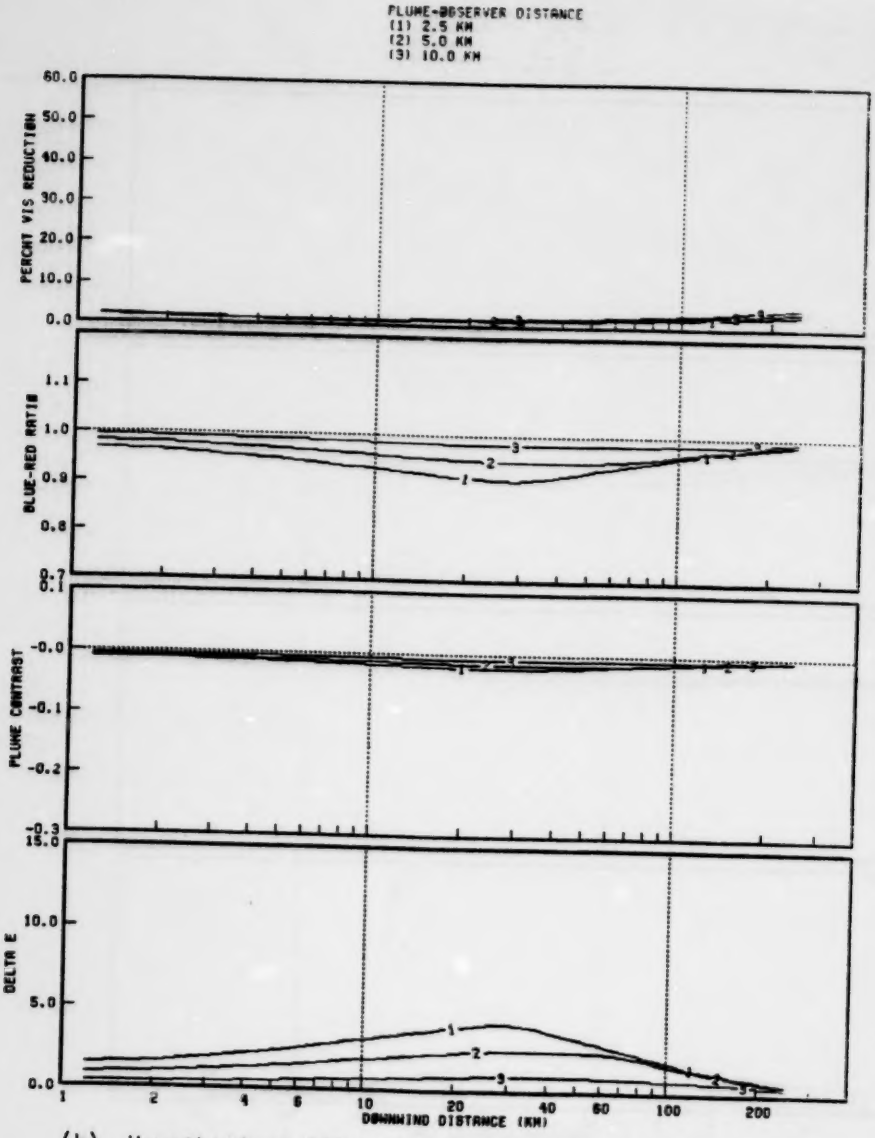
(f) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability E

FIGURE 4 (Continued)



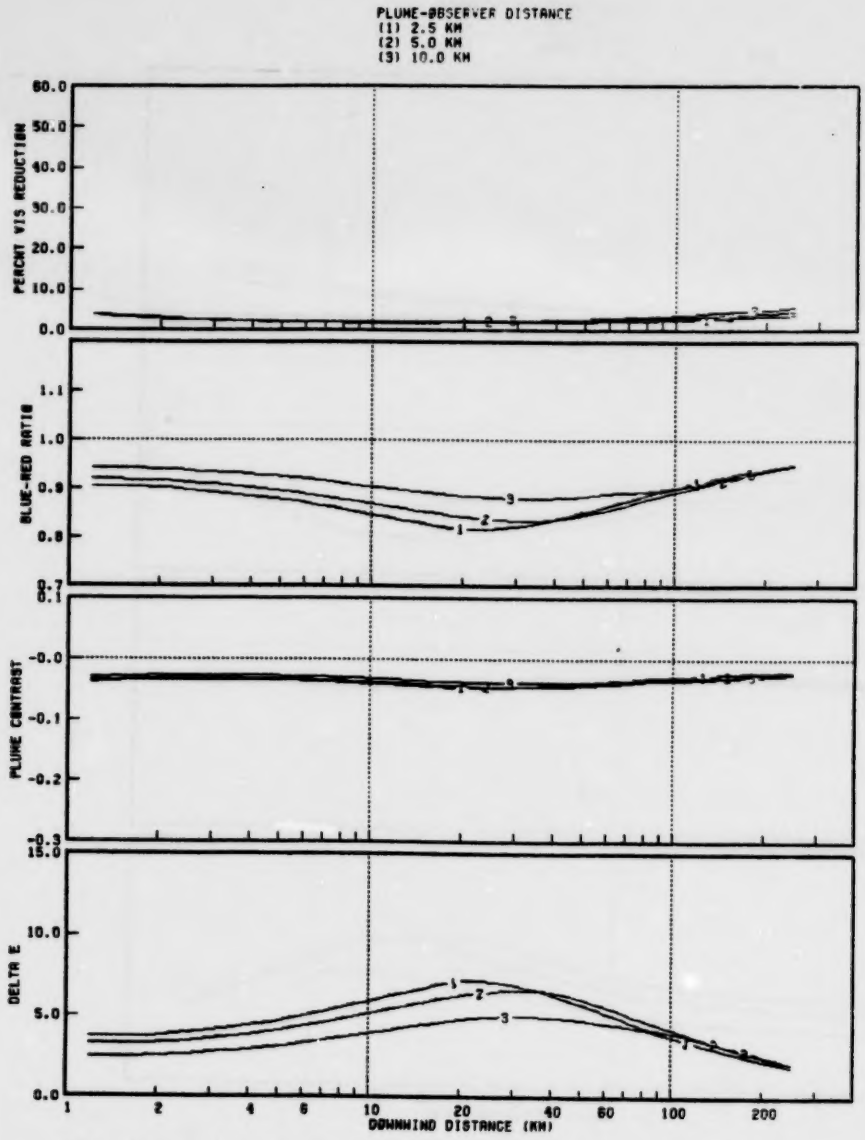
(g) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability D

FIGURE 4 (Continued)



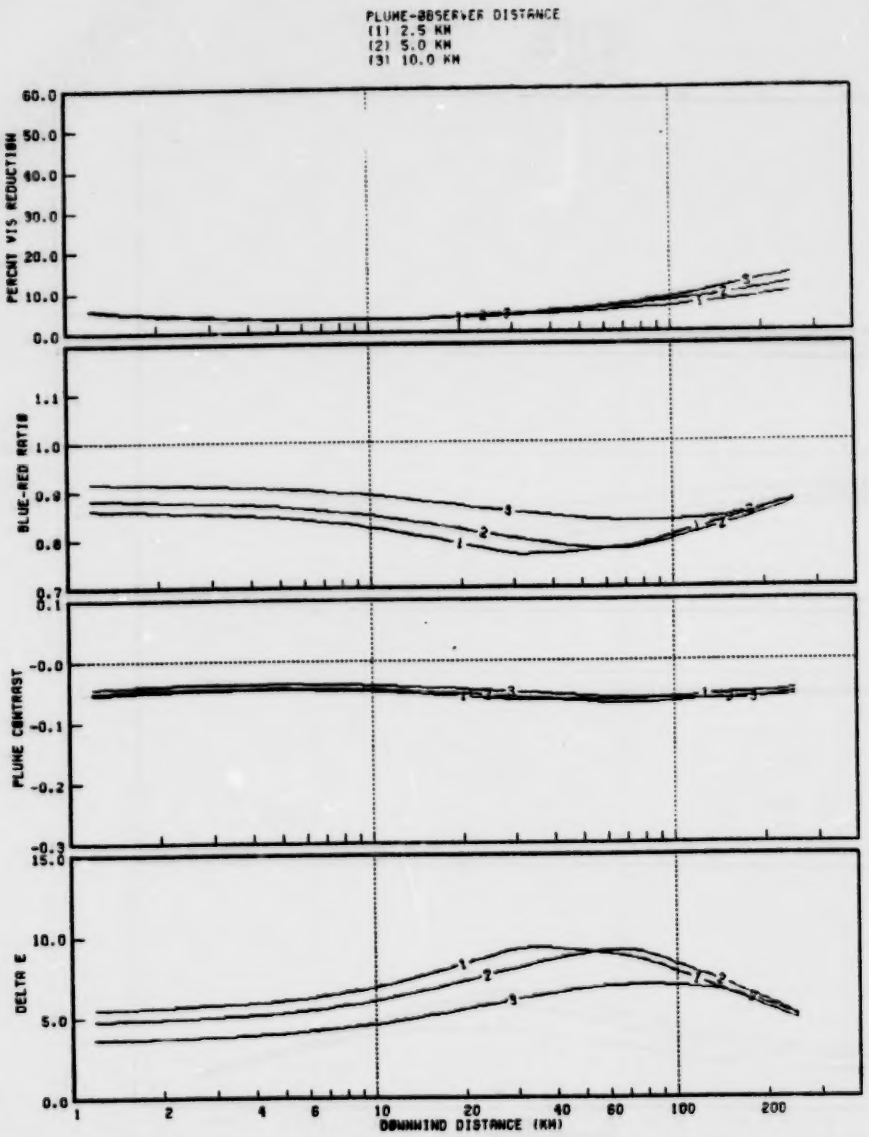
(h) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability E

FIGURE 4 (Continued)



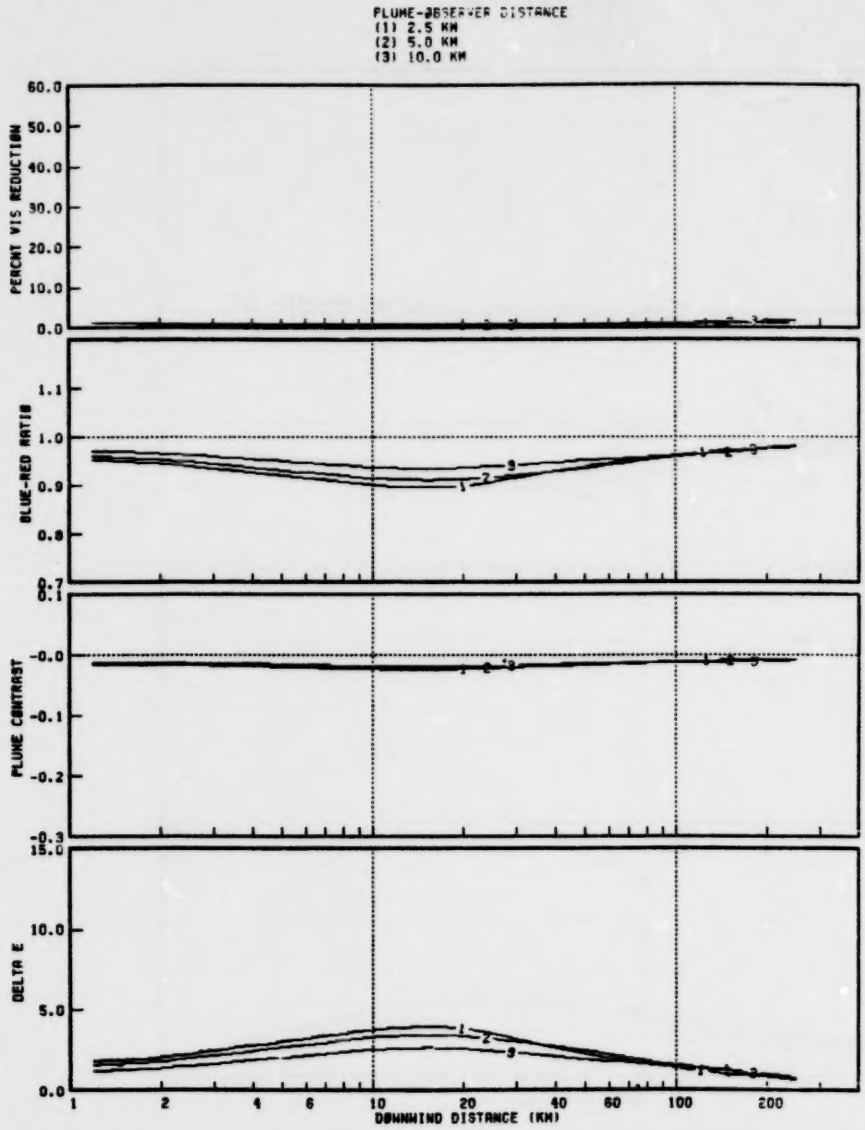
(i) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability D

FIGURE 4 (Continued)



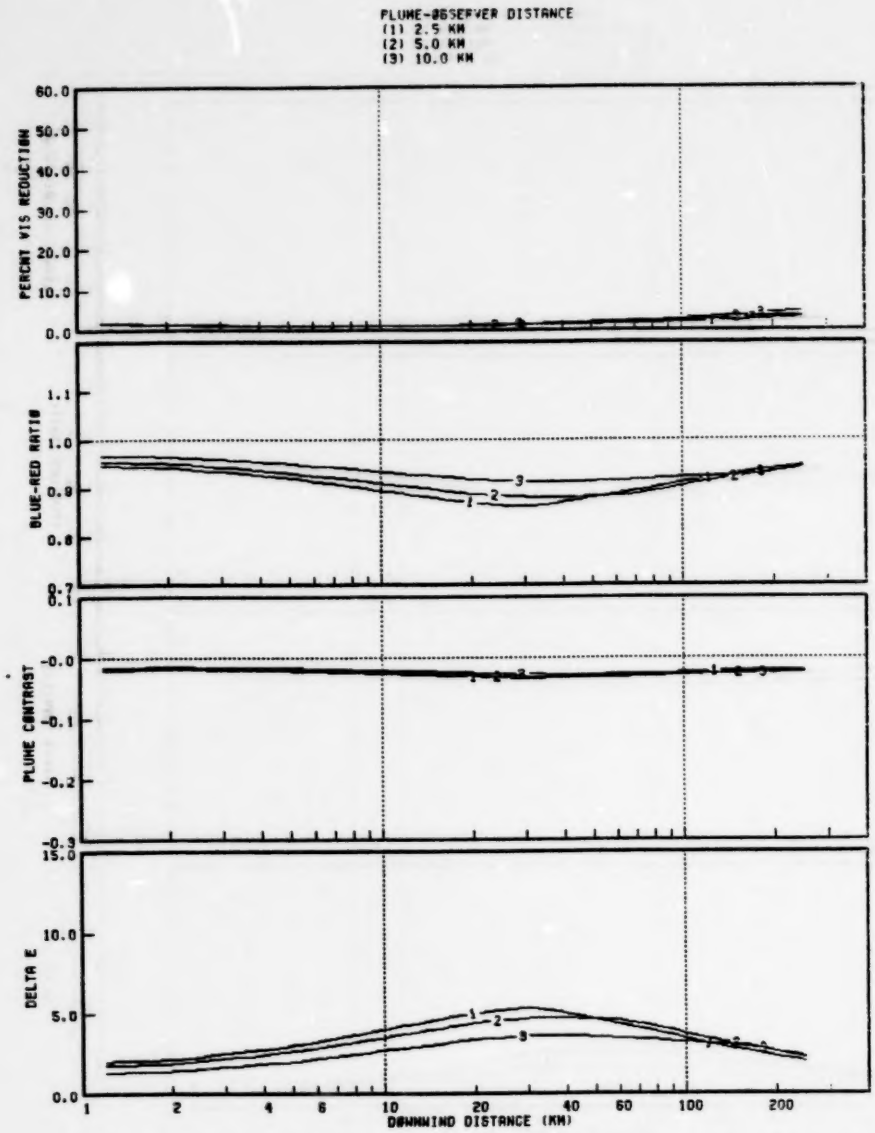
(j) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability E

FIGURE 4 (Continued)



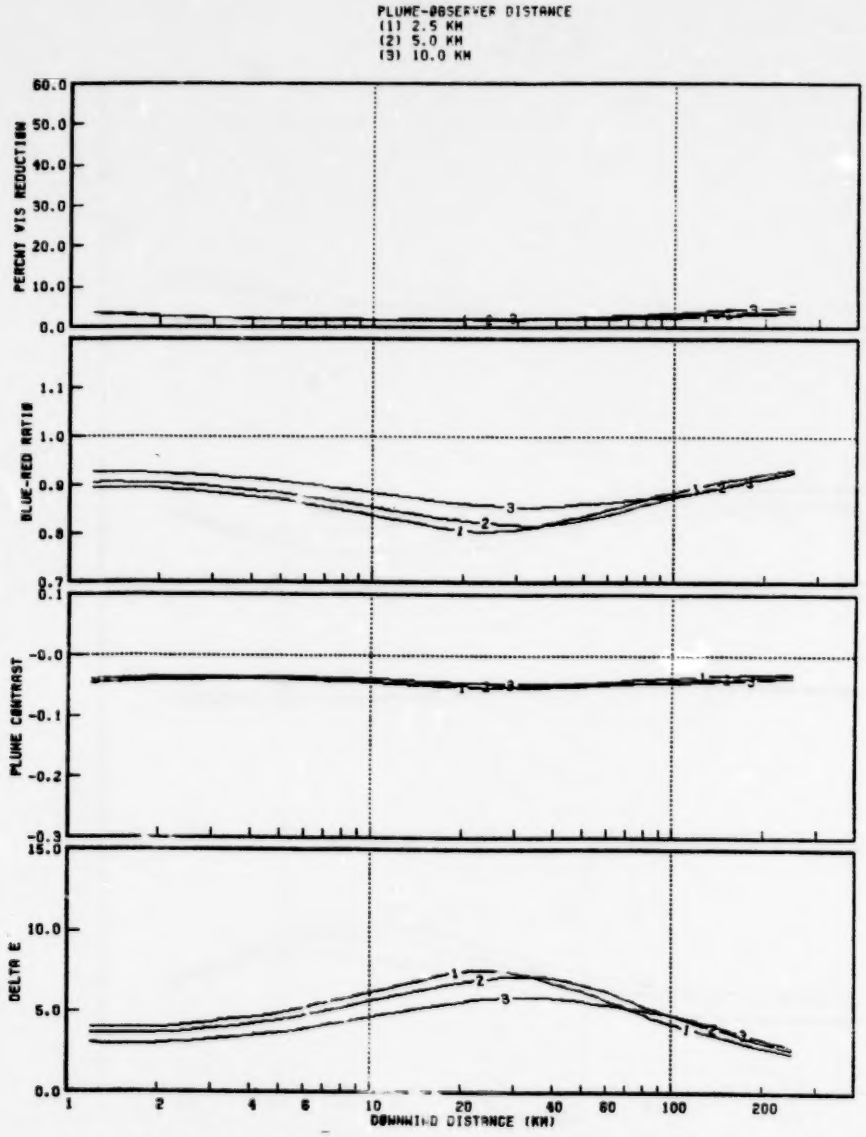
(k) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability D

FIGURE 4 (Continued)



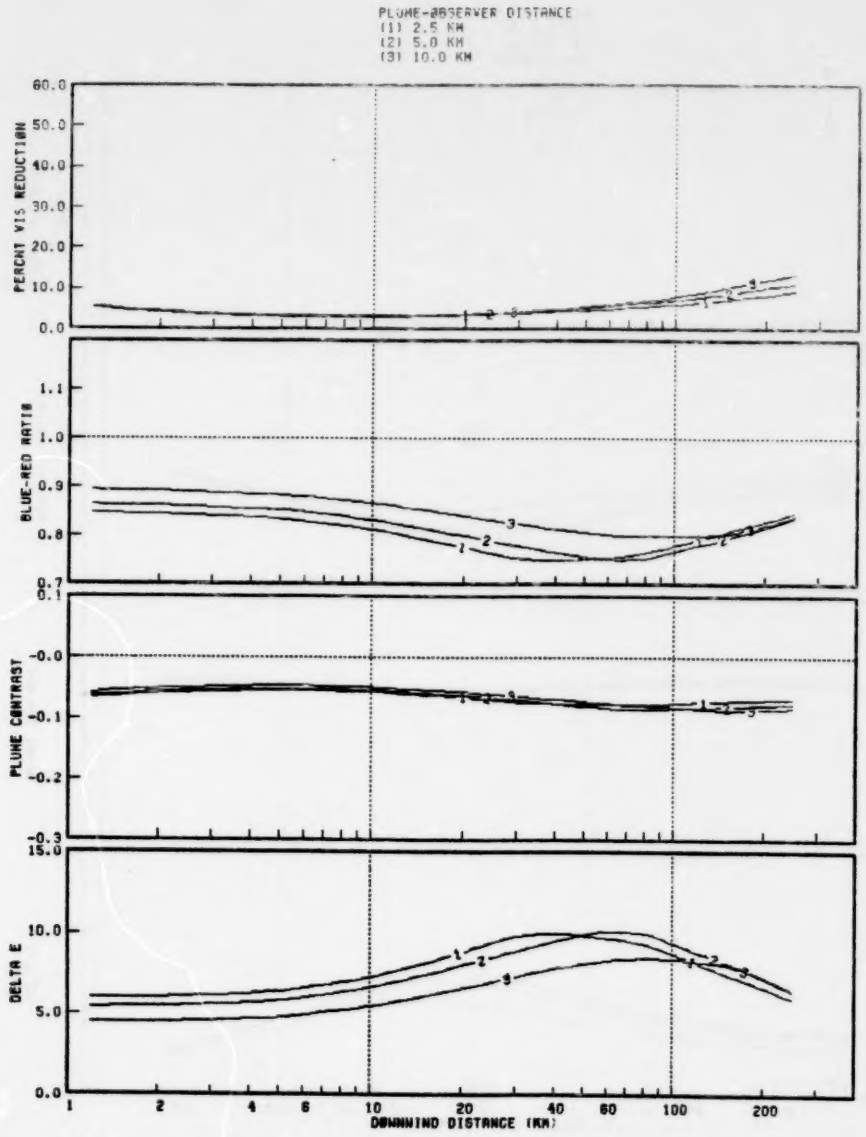
(1) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability E

FIGURE 4 (Continued)



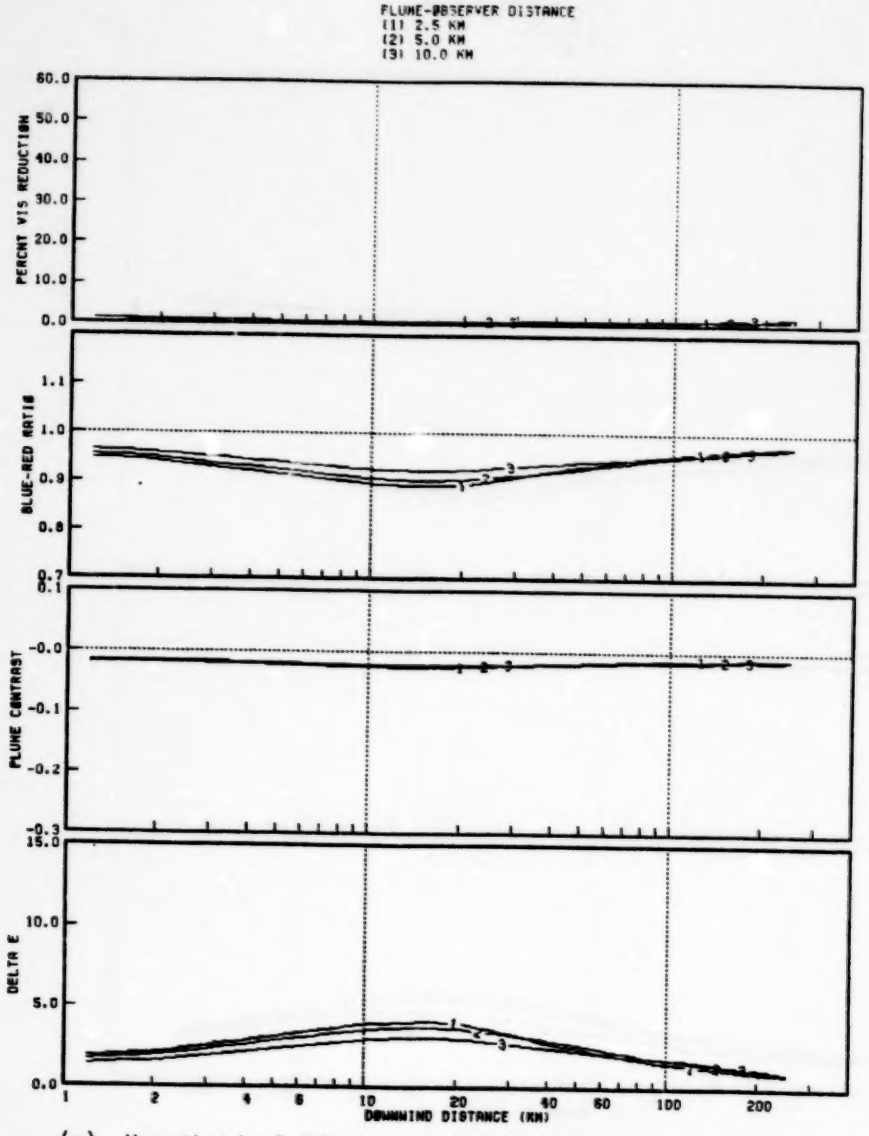
(m) Hypothetical 2250-Mwe (-Fired Power Plant; Best Western Ambient Conditi ith Pasquill Stability D

FIGURE 4 (Continued,



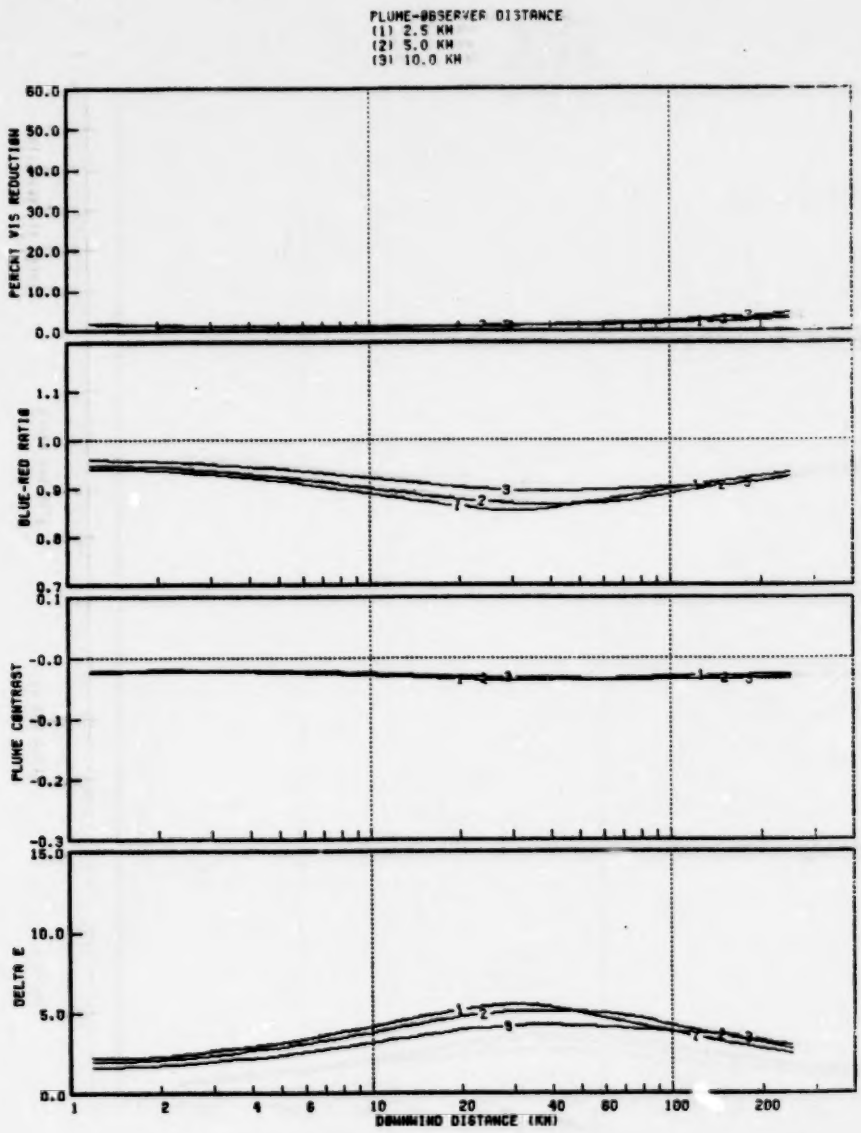
(n) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability E

FIGURE 4 (Continued)



(o) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability D

FIGURE 4 (Continued)



(p) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability E

FIGURE 4 (Concluded)

VI EFFECT OF SO_2-TO-SULFATE CONVERSION RATE ON VISIBILITY IMPAIRMENT

Figures 5(a) through 5(p) illustrate the effect of the rate of SO_2-to-sulfate conversion on visibility impairment. Three rates were evaluated: 5, 0.5, and 0 percent per hour.* The most significant effect of fast sulfate formation (5 percent/hr) is the dramatic reduction in visual range, particularly at far downwind distances; for example, the 2250-Mwe power plant would cause a 25 percent reduction in visual range as shown in Figure 5(a) at 100 km downwind during neutral conditions (Pasquill D), and greater than a 60 percent reduction, as shown in Figure 5(b), during stable conditions (Pasquill E). In some instances (particularly for the eastern U.S. cases) the plume becomes less perceptible with the assumptions of faster sulfate formation because of the color-masking effect of additional scattered light; however, in other cases (notably under the western U.S. conditions with good background visual range), the larger sulfate concentrations resulting from fast SO_2-to-sulfate conversion will cause a more noticeable grey plume or haze.

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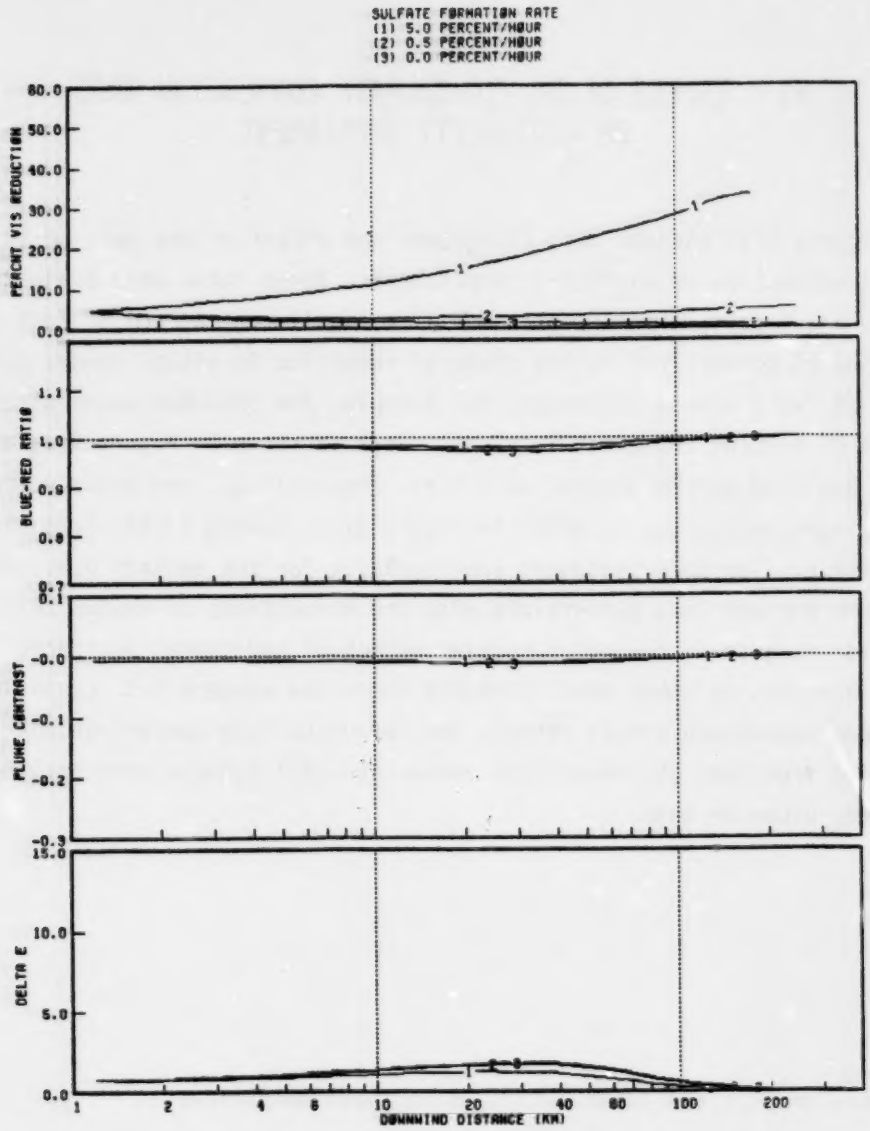
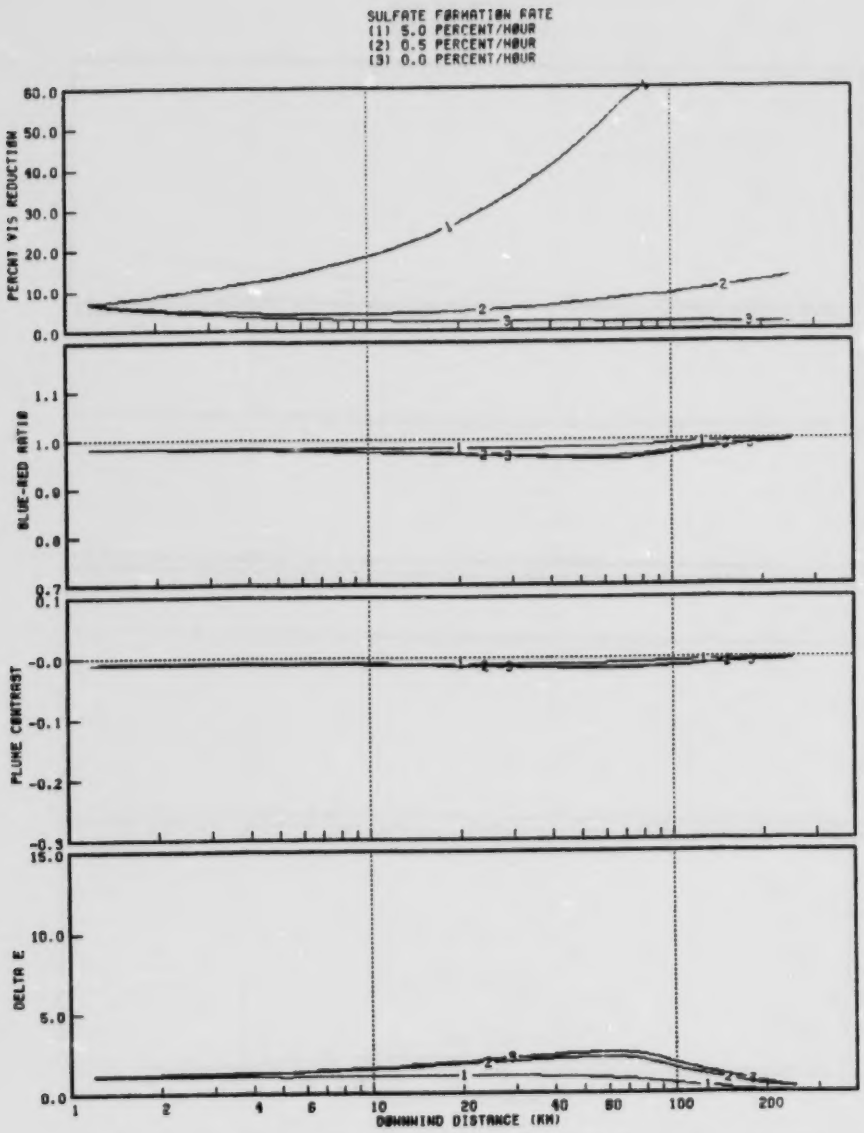
* See key on p. v and Table 1 on p. 5 for base conditions.



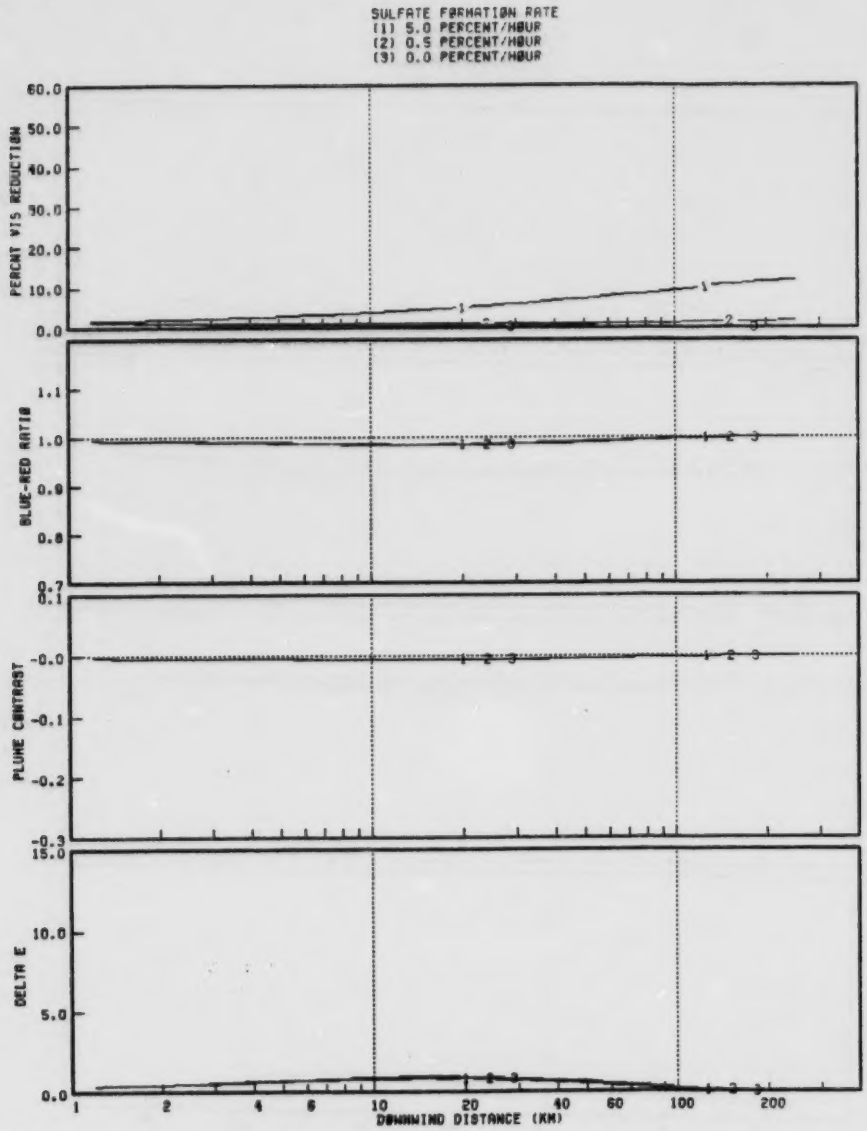
(a) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability D

FIGURE 5. EFFECT OF SULFATE FORMATION ON CALCULATED PLUME VISIBILITY IMPAIRMENT



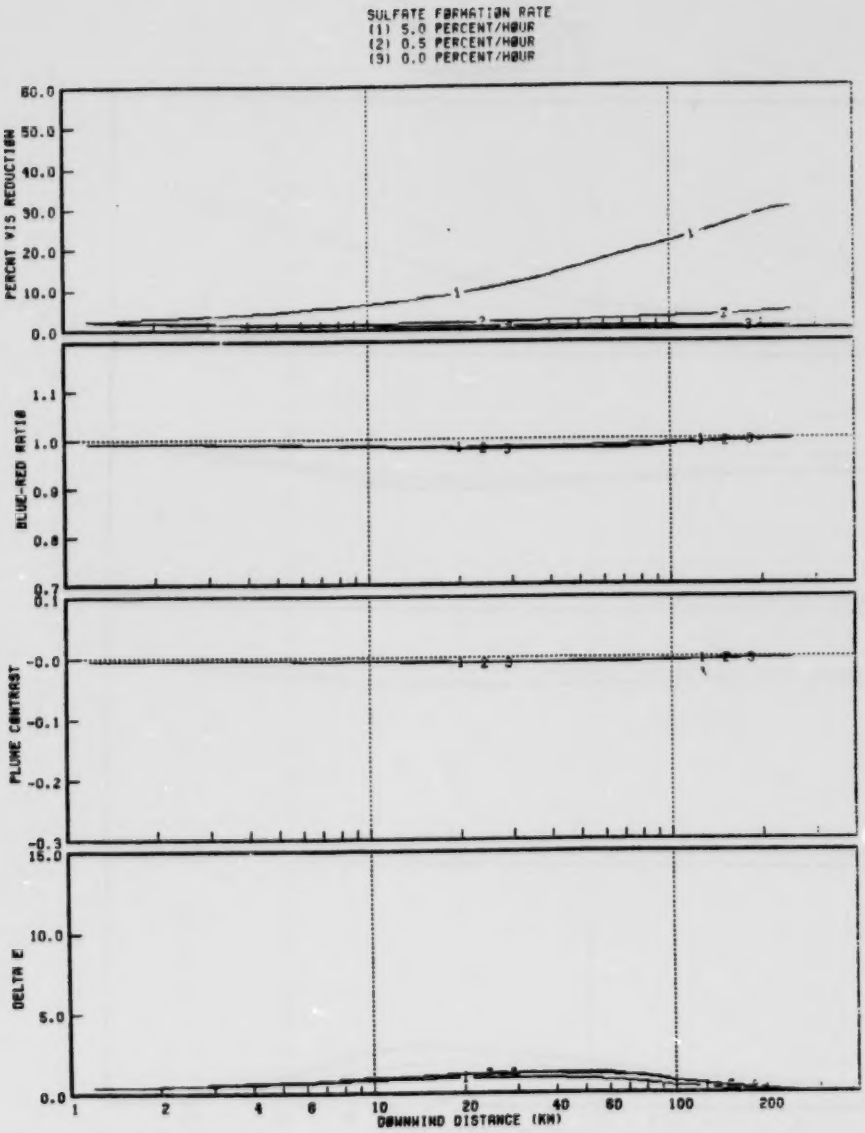
(b) Hypothetical 2250-Mwe Coal Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability E

FIGURE 5 (Continued)



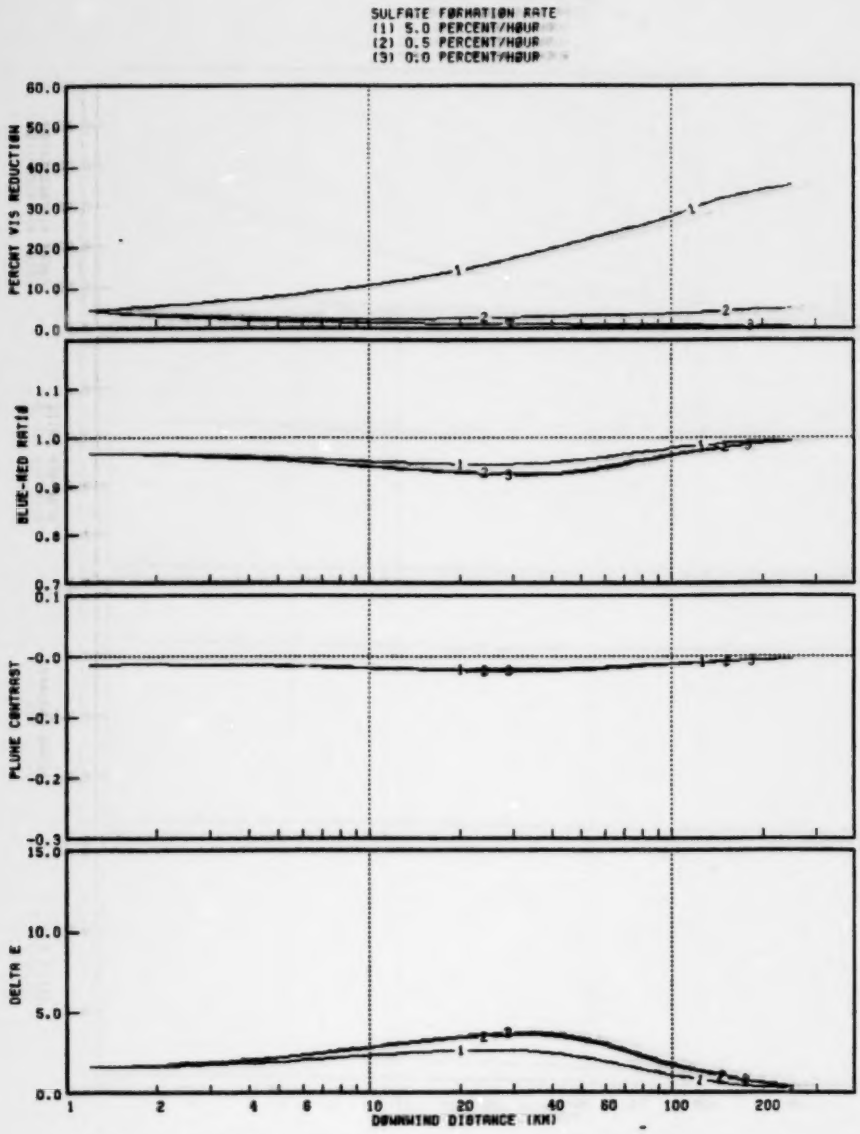
(c) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability D

FIGURE 5 (Continued)



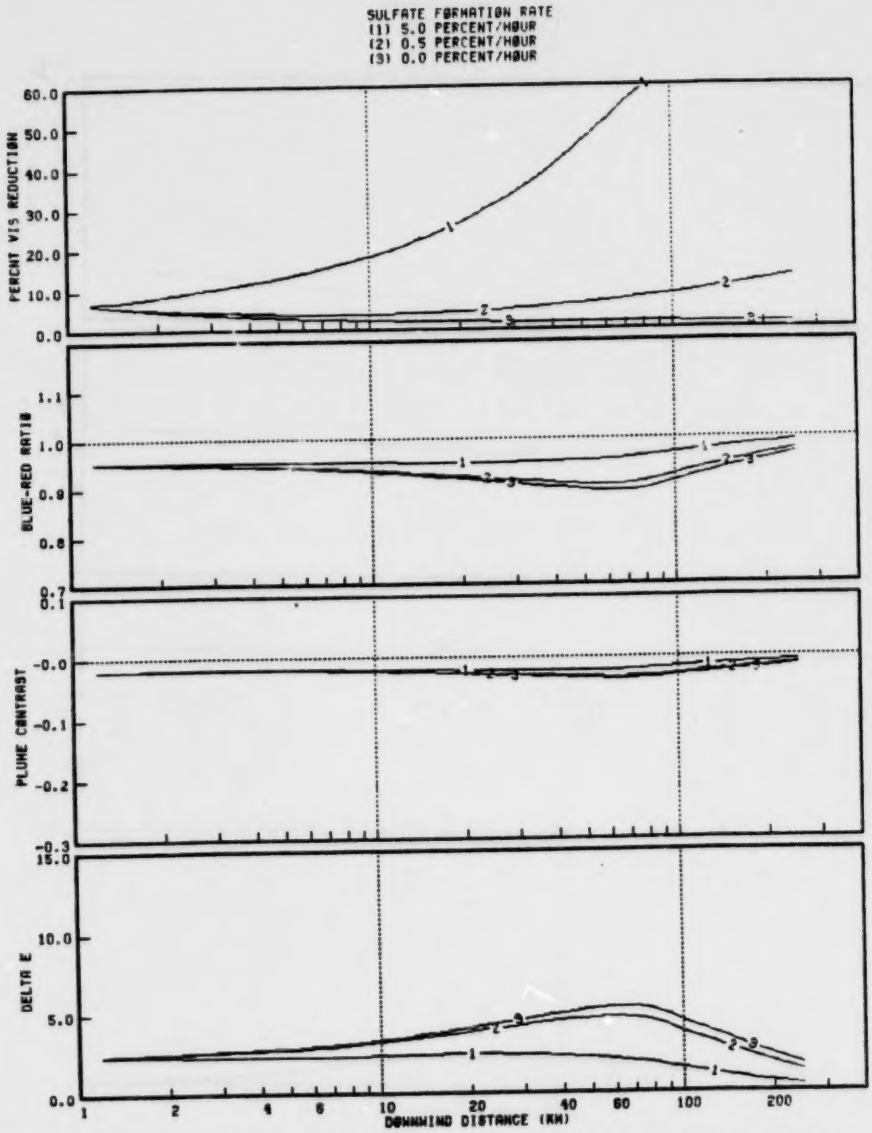
(d) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability E

FIGURE 5 (Continued)



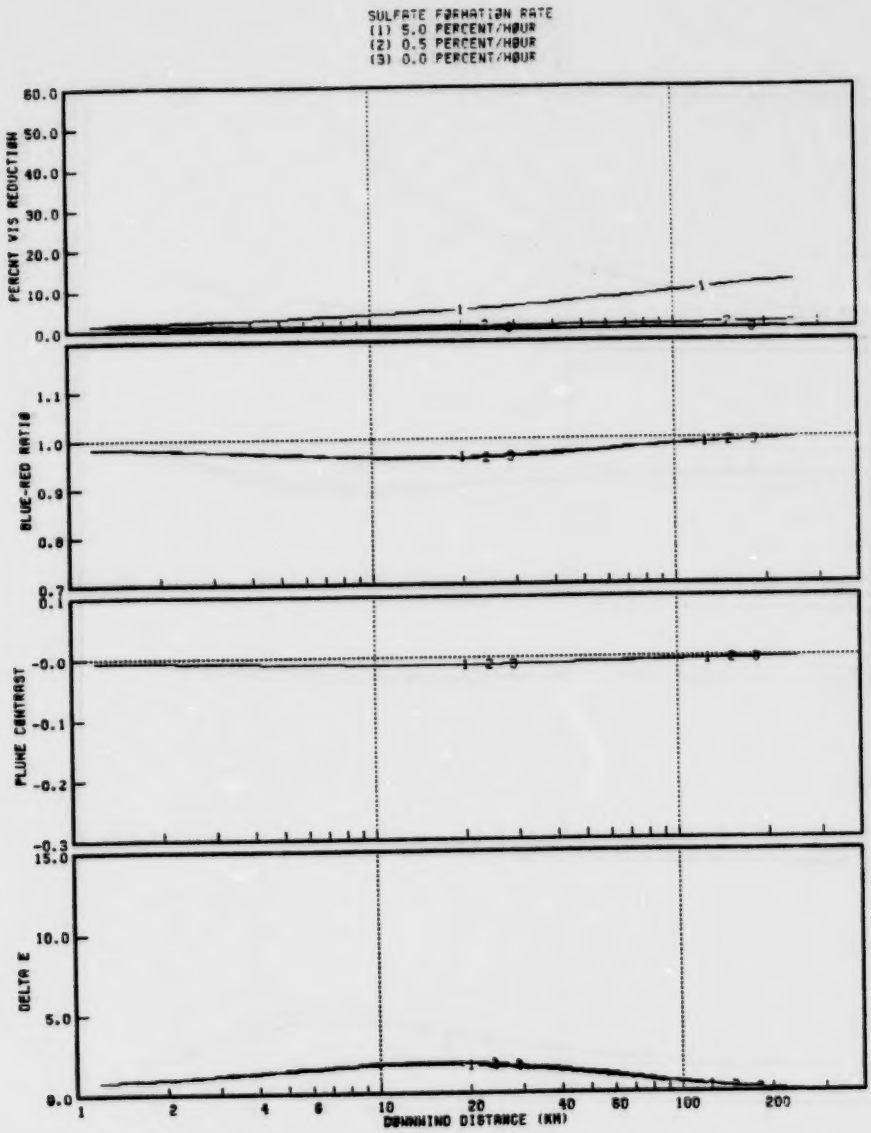
(e) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability D

FIGURE 5 (Continued)



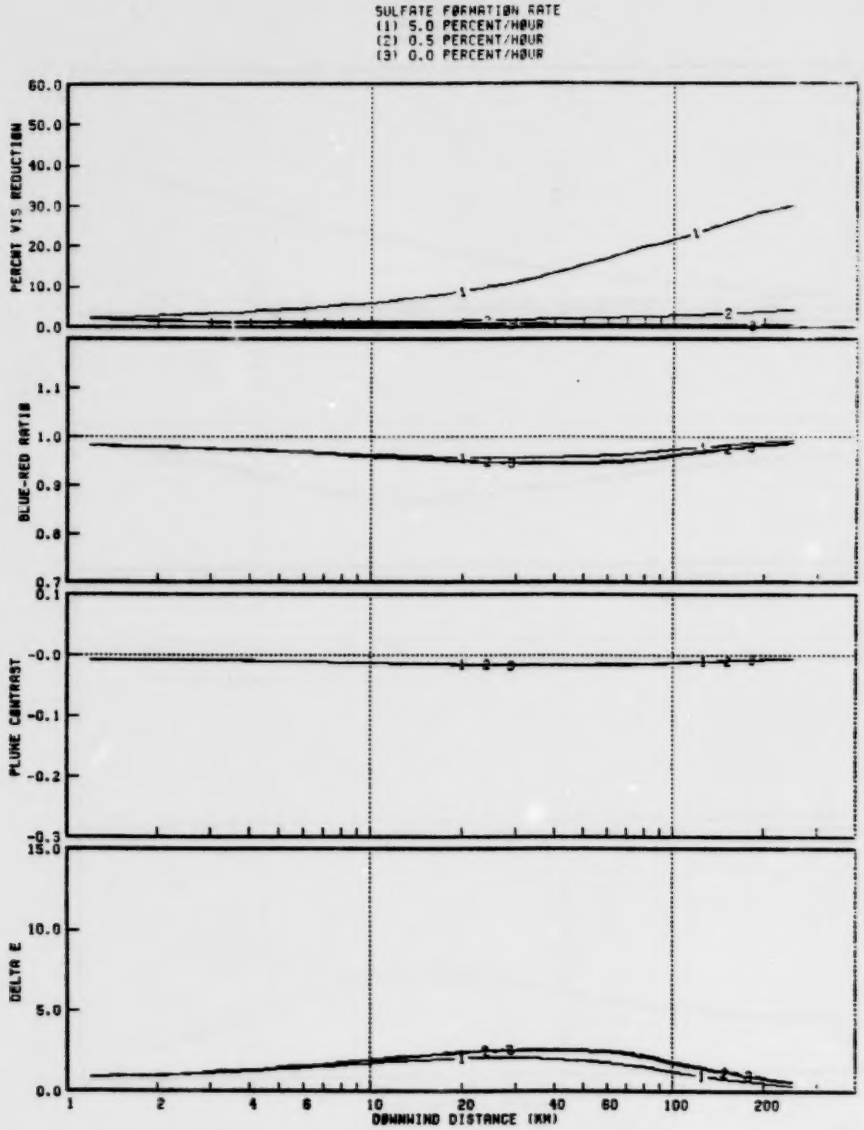
(f) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability E

FIGURE 5 (Continued)



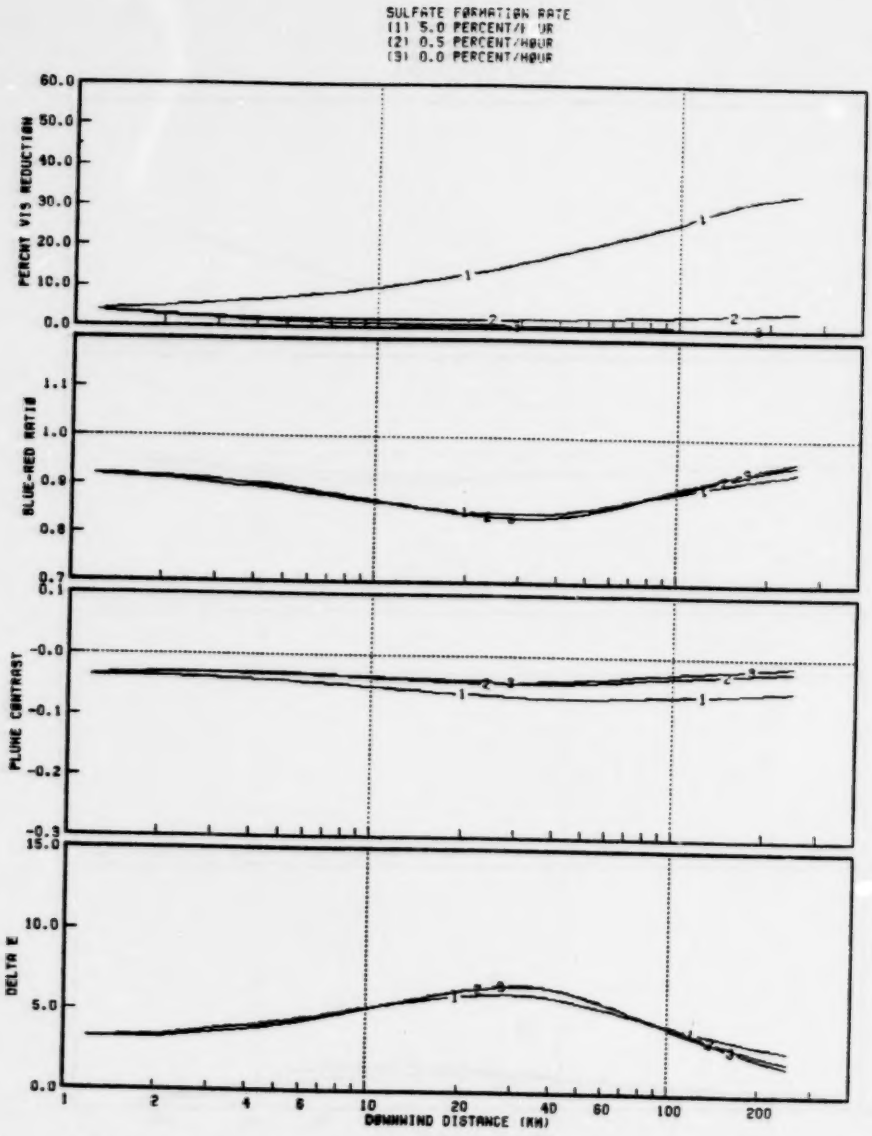
(g) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability D

FIGURE 5 (Continued)



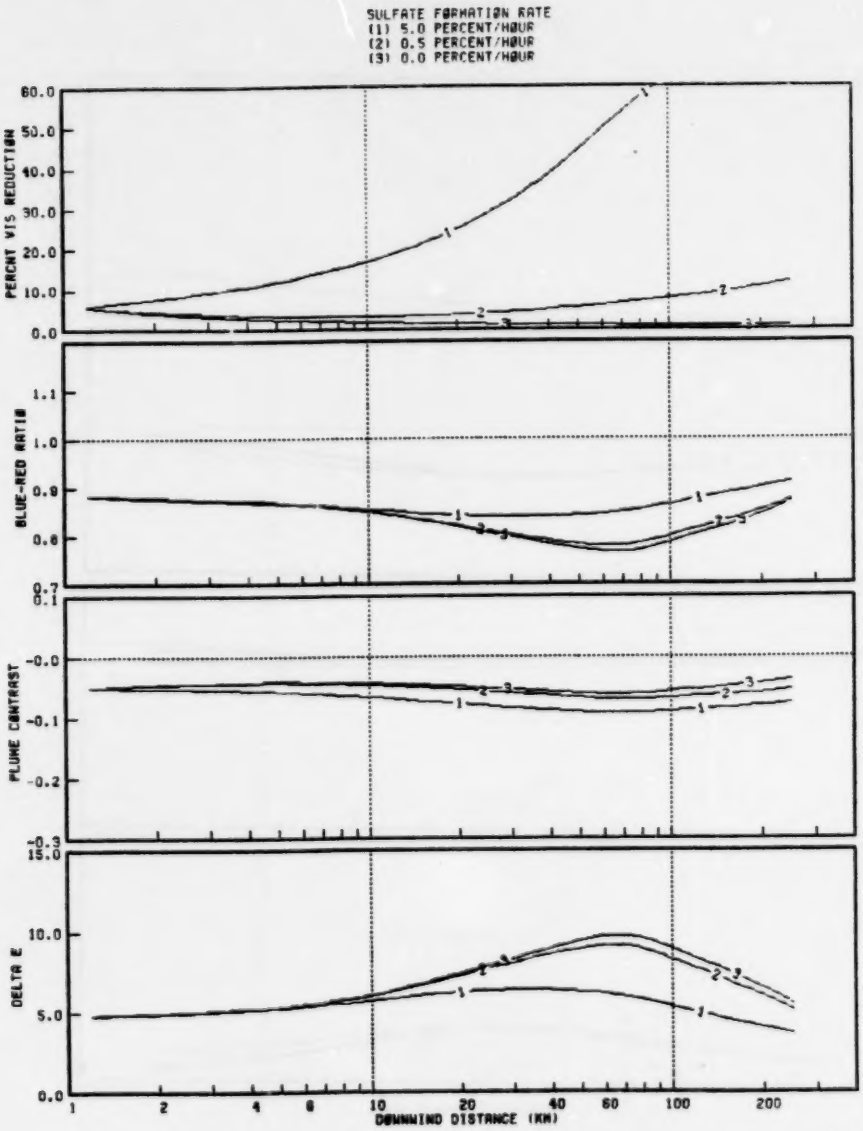
(h) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability E

FIGURE 5 (Continued)



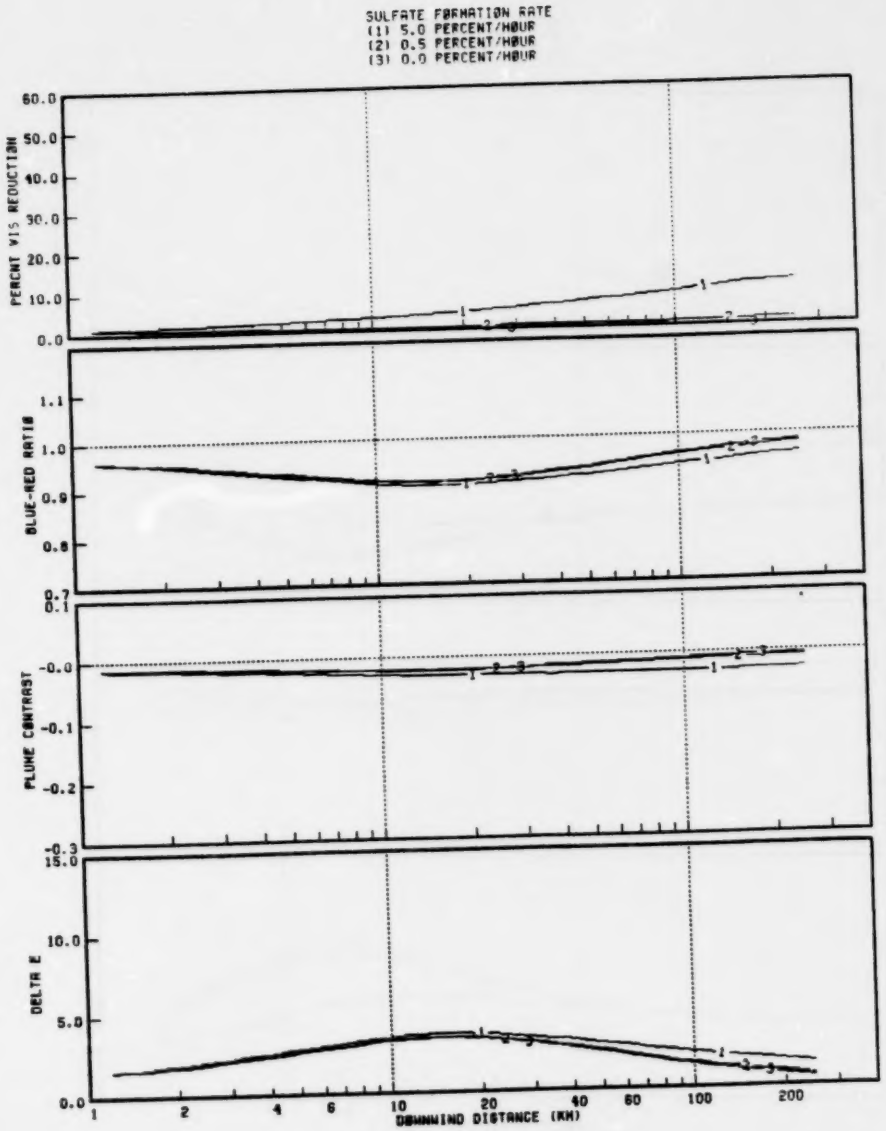
(i) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability D

FIGURE 5 (Continued)



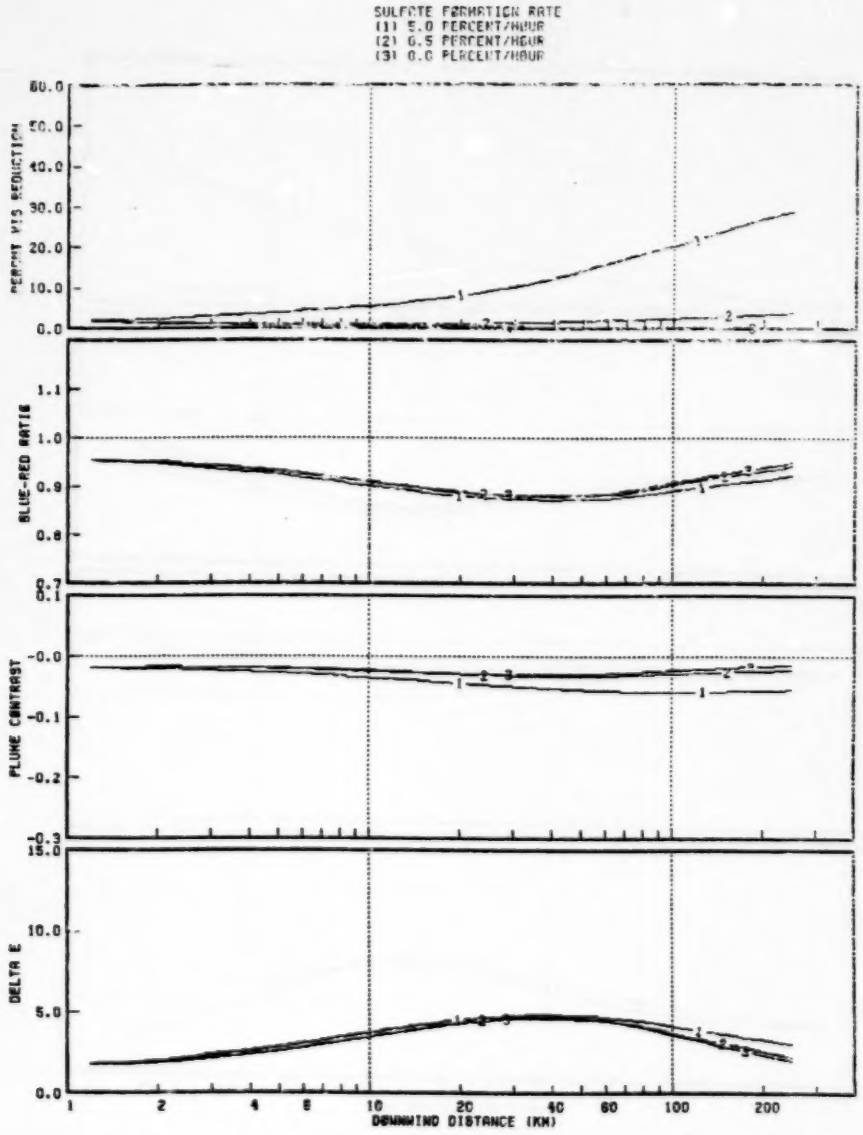
(j) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability E

FIGURE 5 (Continued)



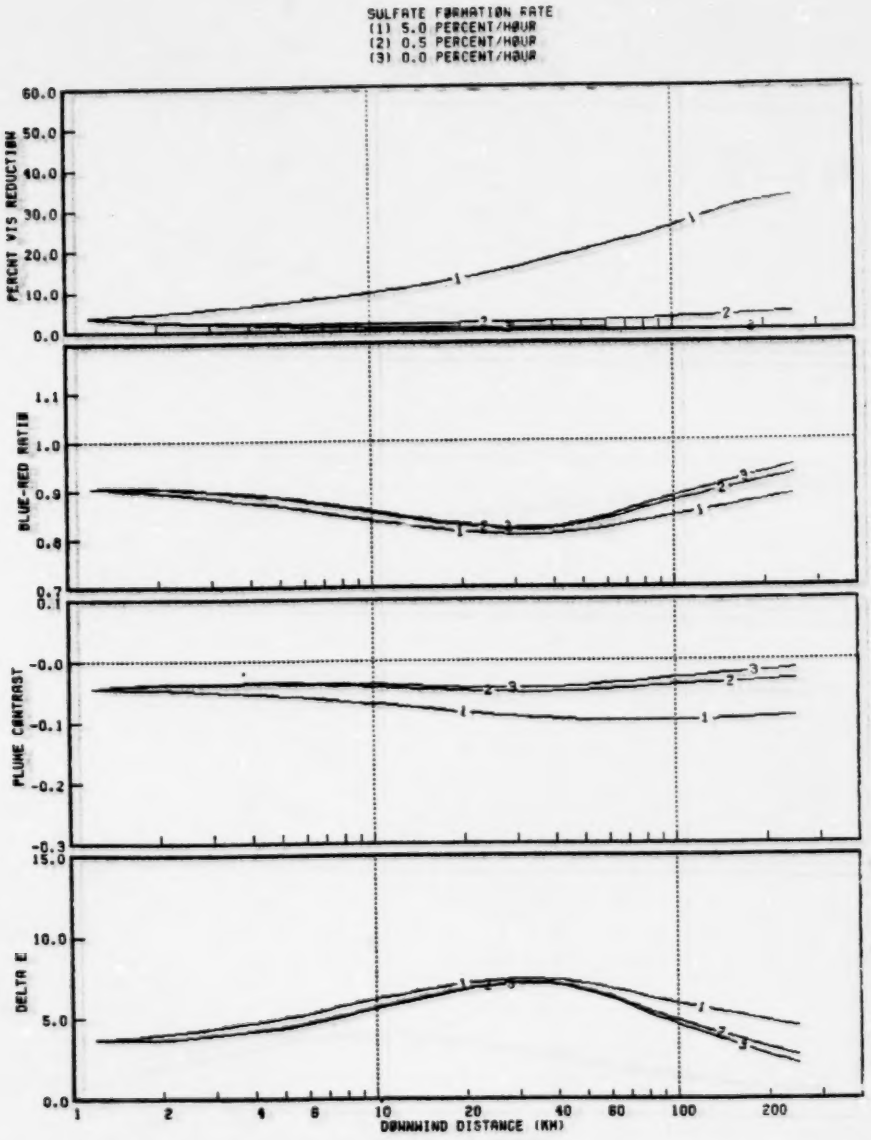
(k) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability D

FIGURE 5 (Continued)



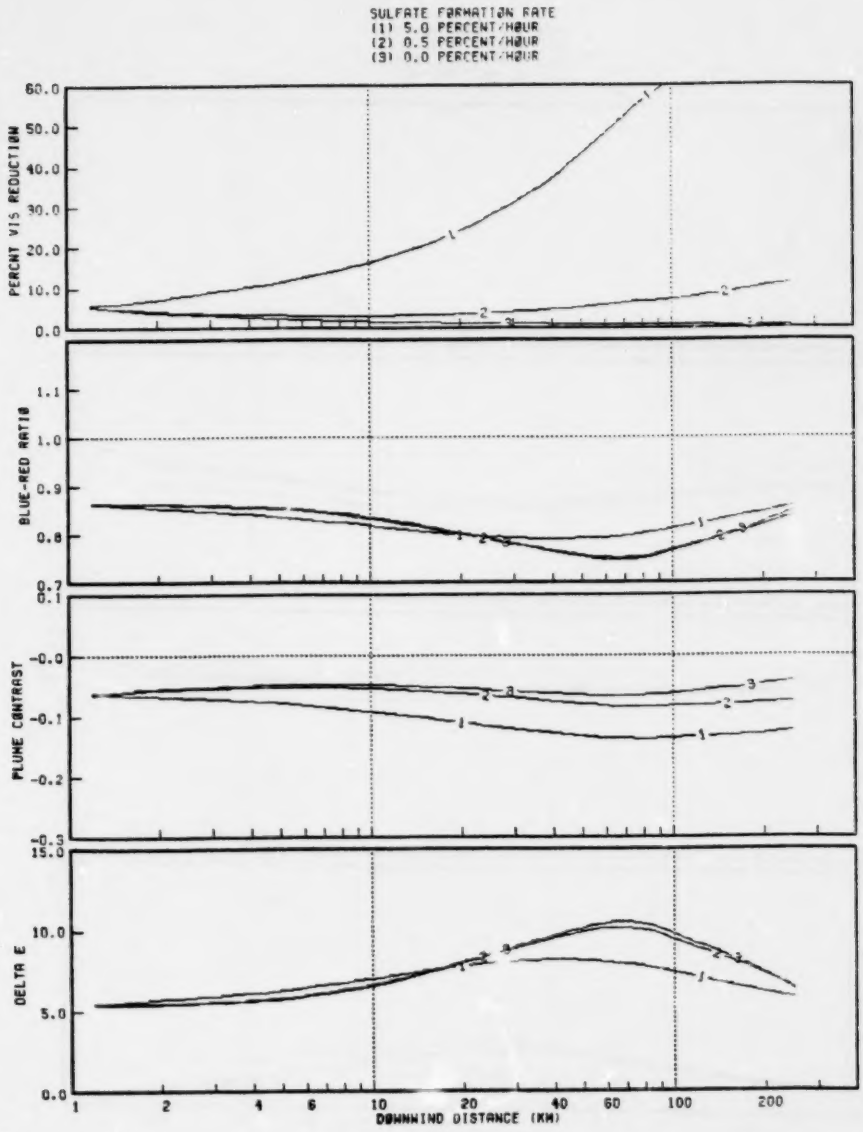
(1) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability E

FIGURE 5 (Continued)



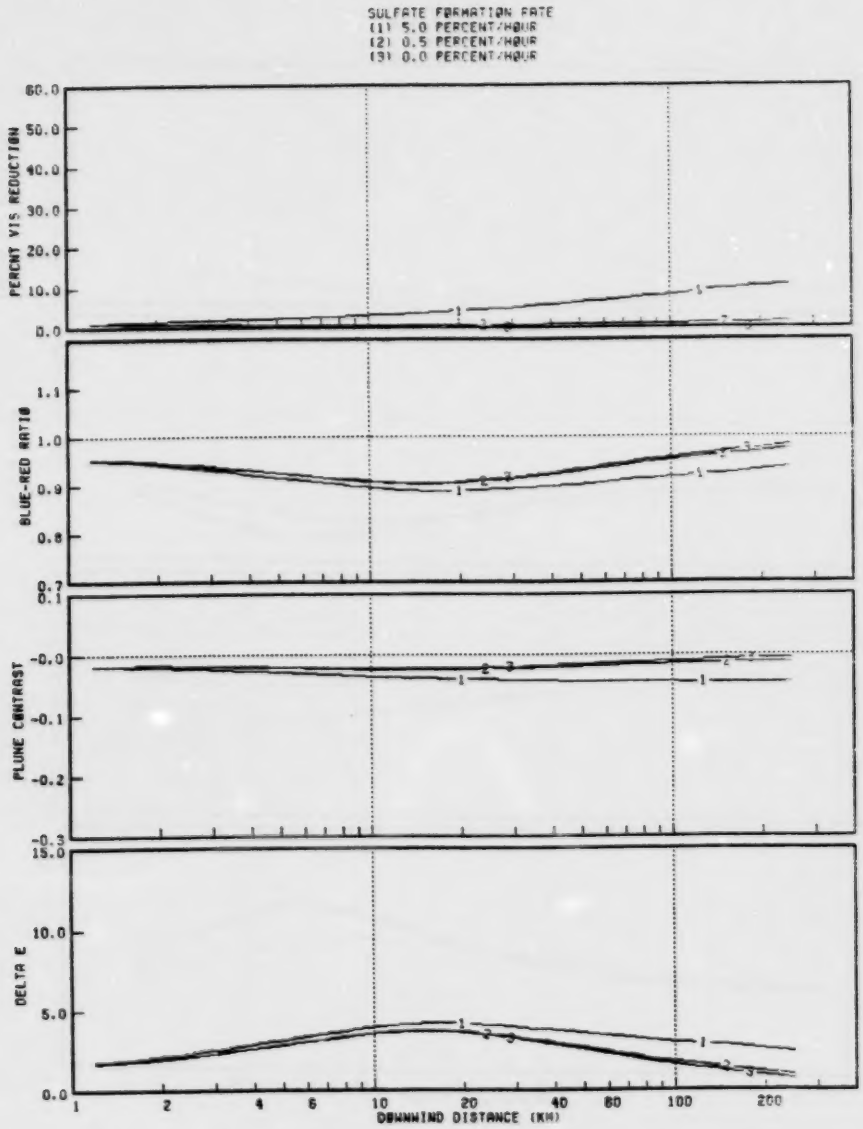
(m) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability D

FIGURE 5 (Continued)



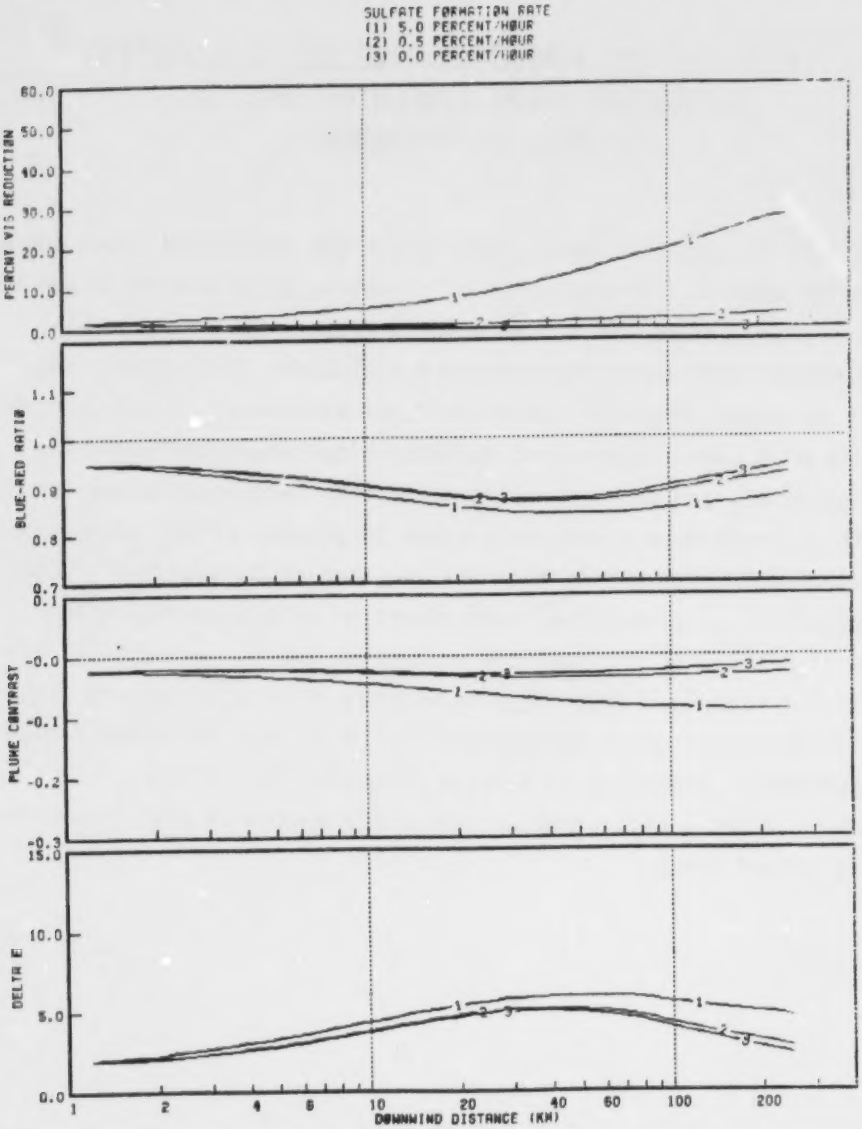
(n) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability E

FIGURE 5 (Continued)



(o) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability D

FIGURE 5 (Continued)



(p) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability E

FIGURE 5 (Concluded)

VII EFFECT OF NO_2 FORMATION RATE DUE TO DIFFERENT BACKGROUND OZONE CONCENTRATIONS ON VISIBILITY IMPAIRMENT

The effect of different assumptions about the background ozone concentration, which affects the conversion of colorless NO to the red-brown NO_2 gas in power plant plumes, is illustrated in Figures 6(a) through 6(p). Three background ozone concentrations were evaluated: 0.12, 0.04, and 0.00 ppm.* An ozone concentration of 0.04 ppm is typical of many nonurban areas, while 0.12 ppm is typical of polluted areas where photochemical reactions among NO_x and reactive hydrocarbon emissions cause ozone formation. With no background ozone, only about 10 percent of NO_x emissions are converted to NO_2 (resulting from the reaction of NO with O_2). Note that increased NO_2 concentrations have almost no effect on the visual range, but significantly increase the coloration and the perceptibility of plumes. For example, Figure 6(j) shows that, with a background visual range of 130 km and an ozone concentration of 0.12 ppm, the plume perceptibility parameter ΔE approaches a value of nearly 15. It should be noted, however, that a high ozone concentration would not likely coincide with a high visual range.

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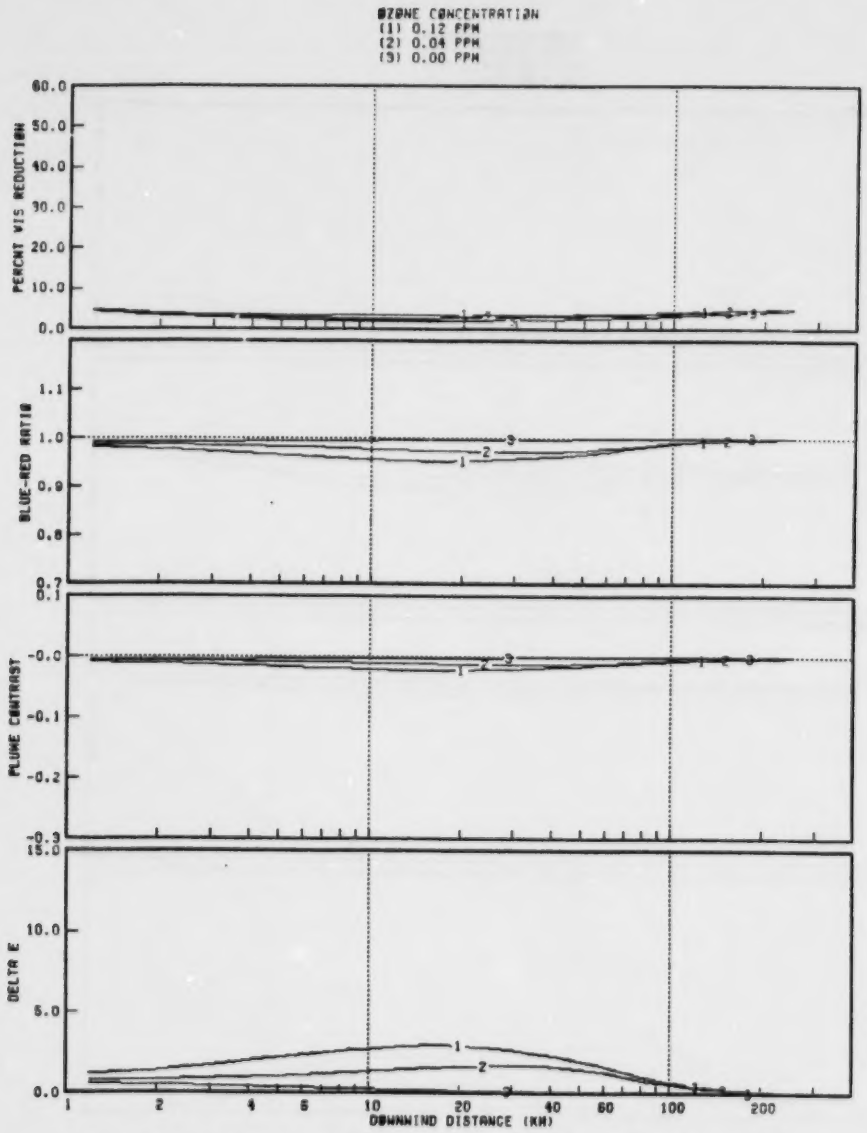
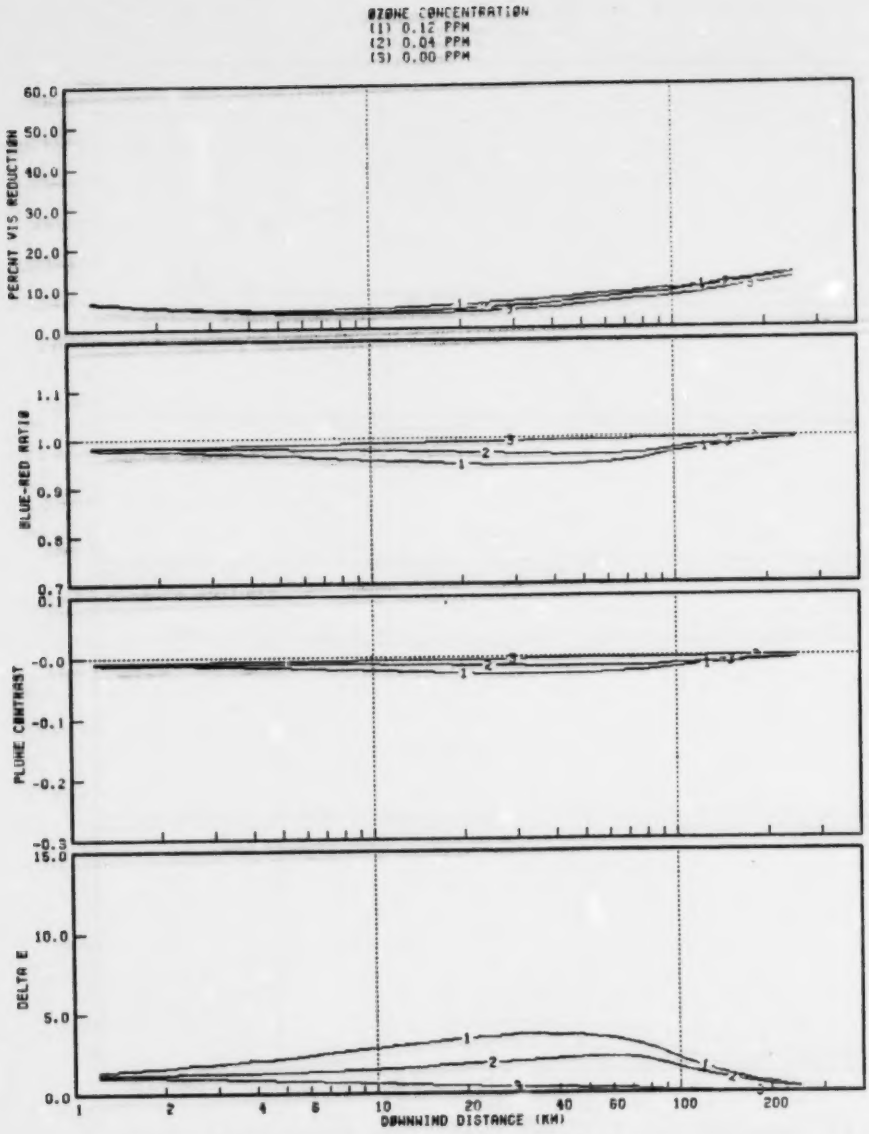
* See key on p. v and Table 1 on p. 5 for base conditions.



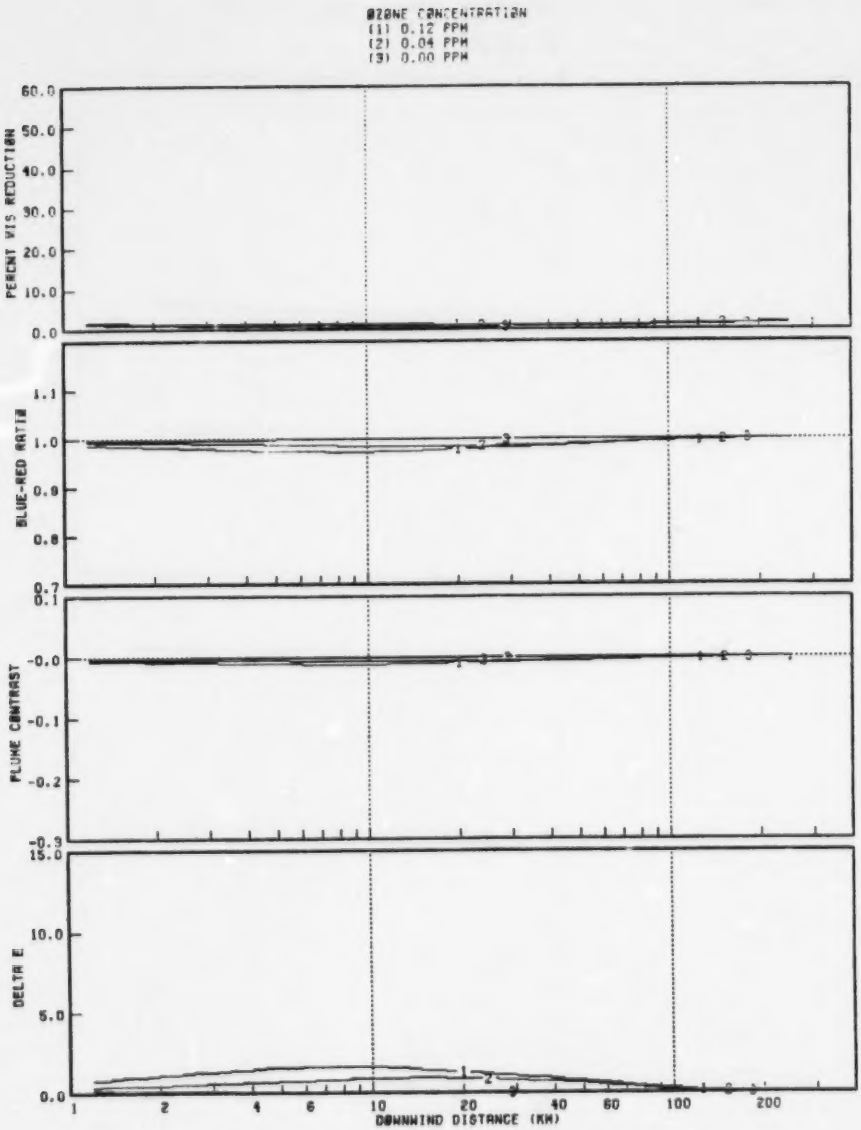
(a) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability D

FIGURE 6. EFFECT OF BACKGROUND OZONE ON CALCULATED PLUME VISIBILITY IMPAIRMENT



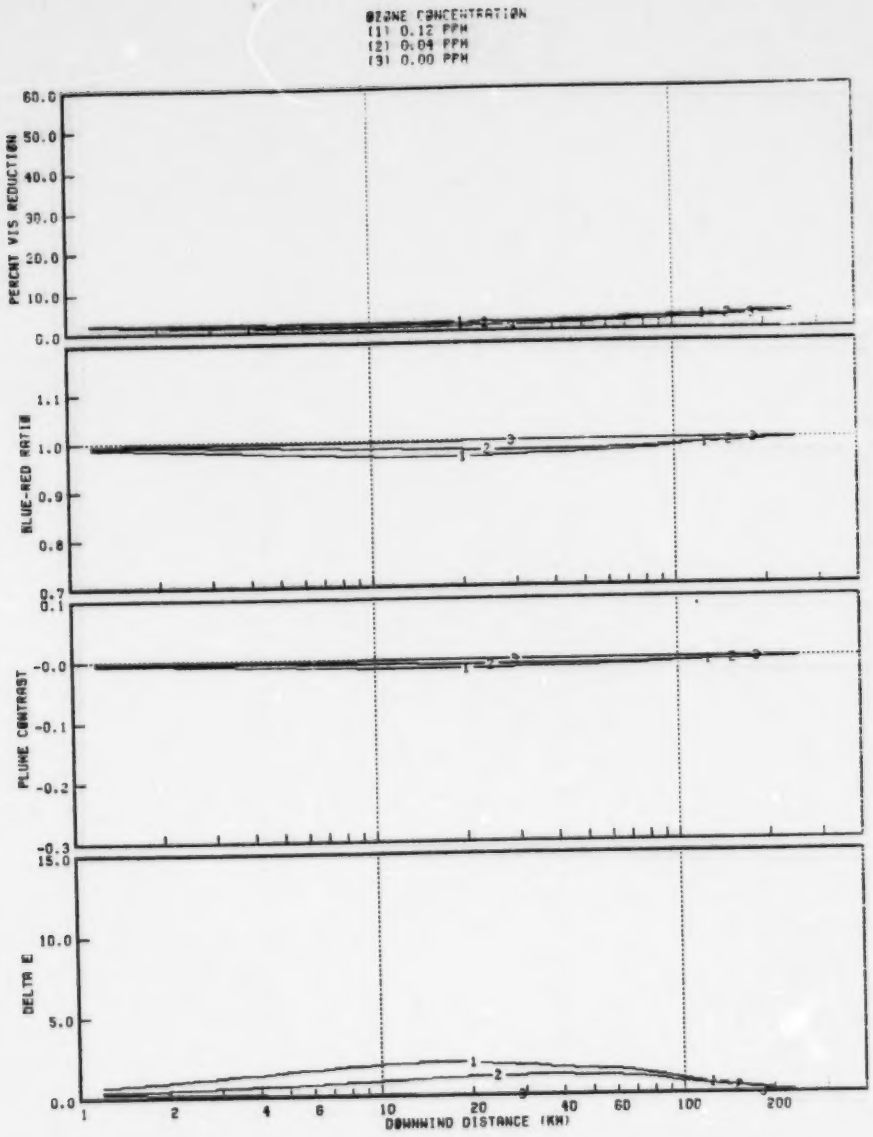
(b) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability E

FIGURE 6 (Continued)



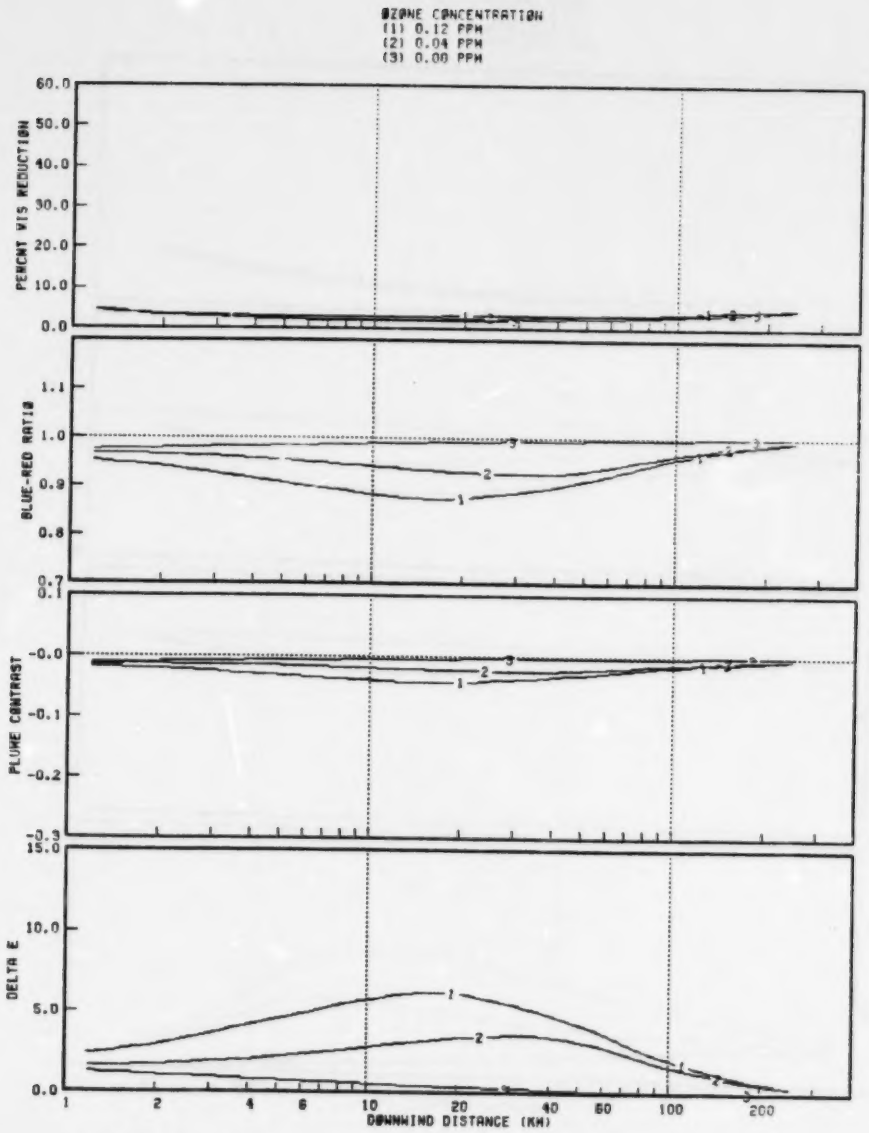
(c) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability D

FIGURE 6 (Continued)



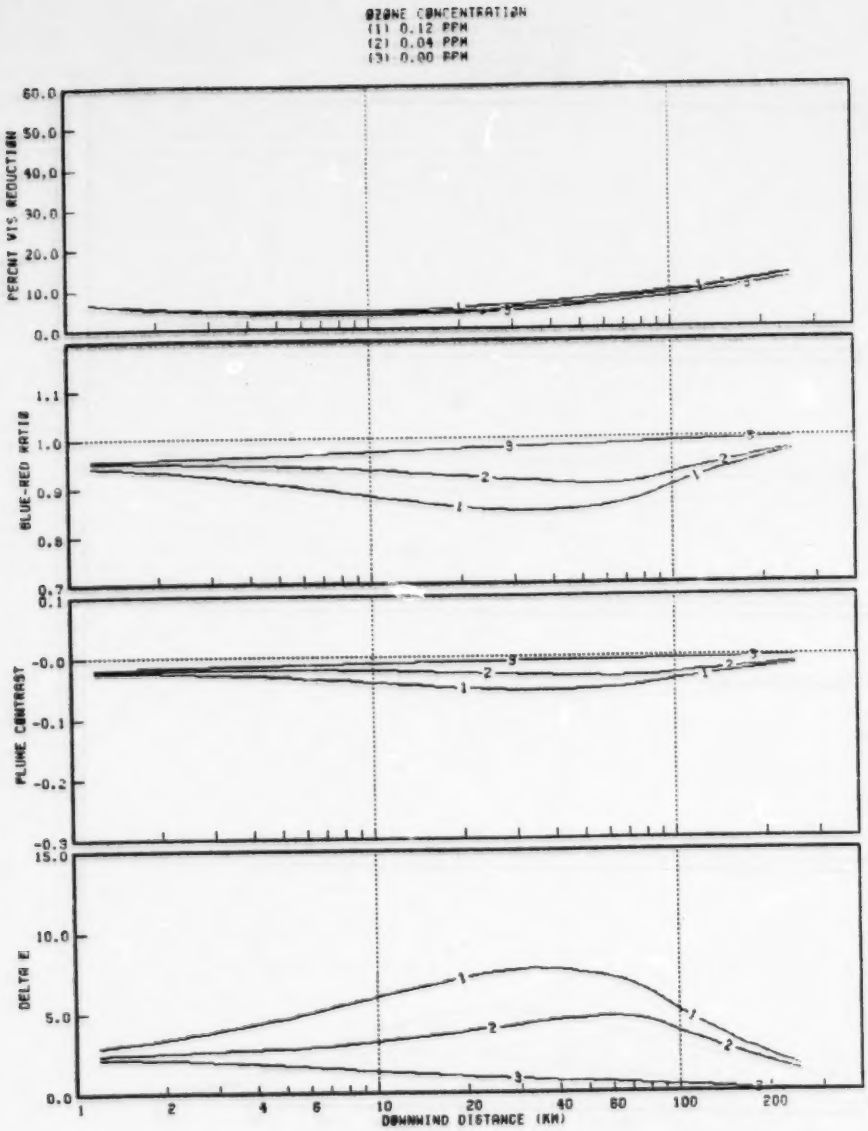
(d) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Eastern Ambient Conditions with Pasquill Stability E

FIGURE 6 (Continued)



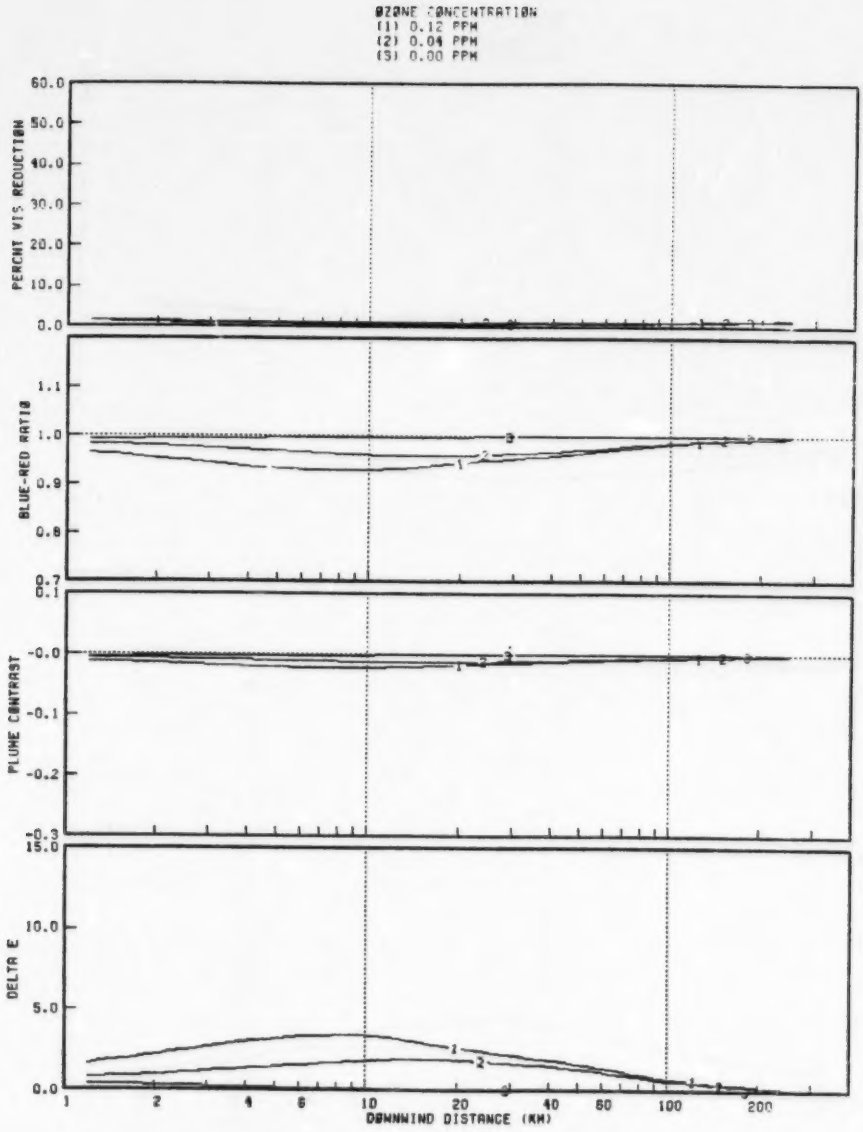
(e) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability D

FIGURE 6 (Continued)



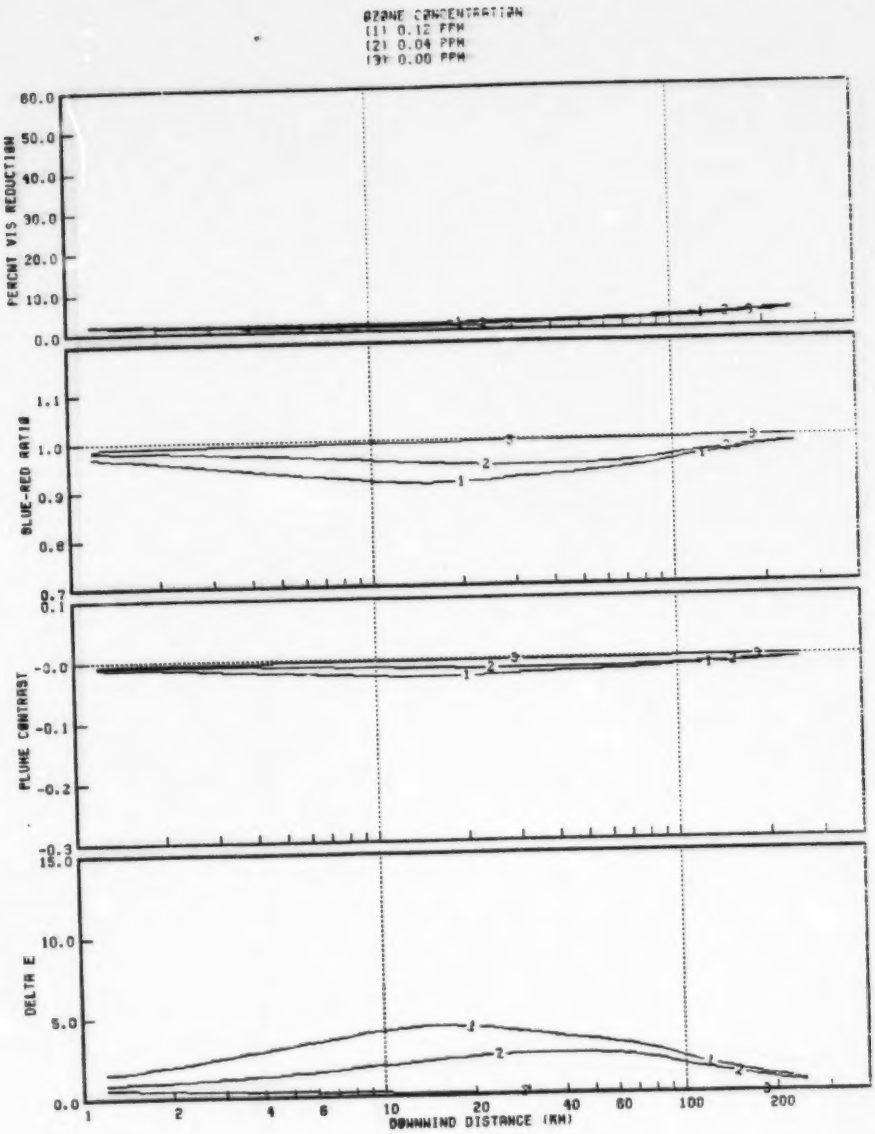
(f) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability E

FIGURE 6 (Continued)



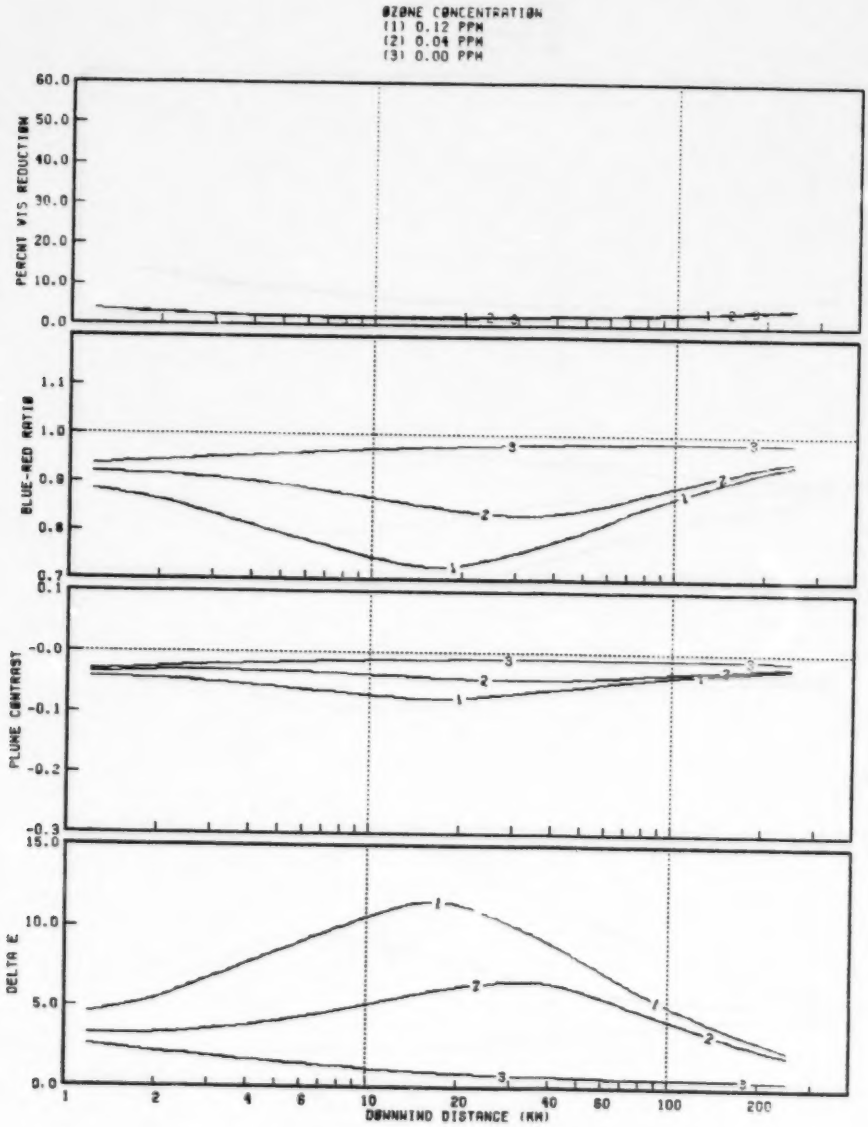
(g) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability D

FIGURE 6 (Continued)



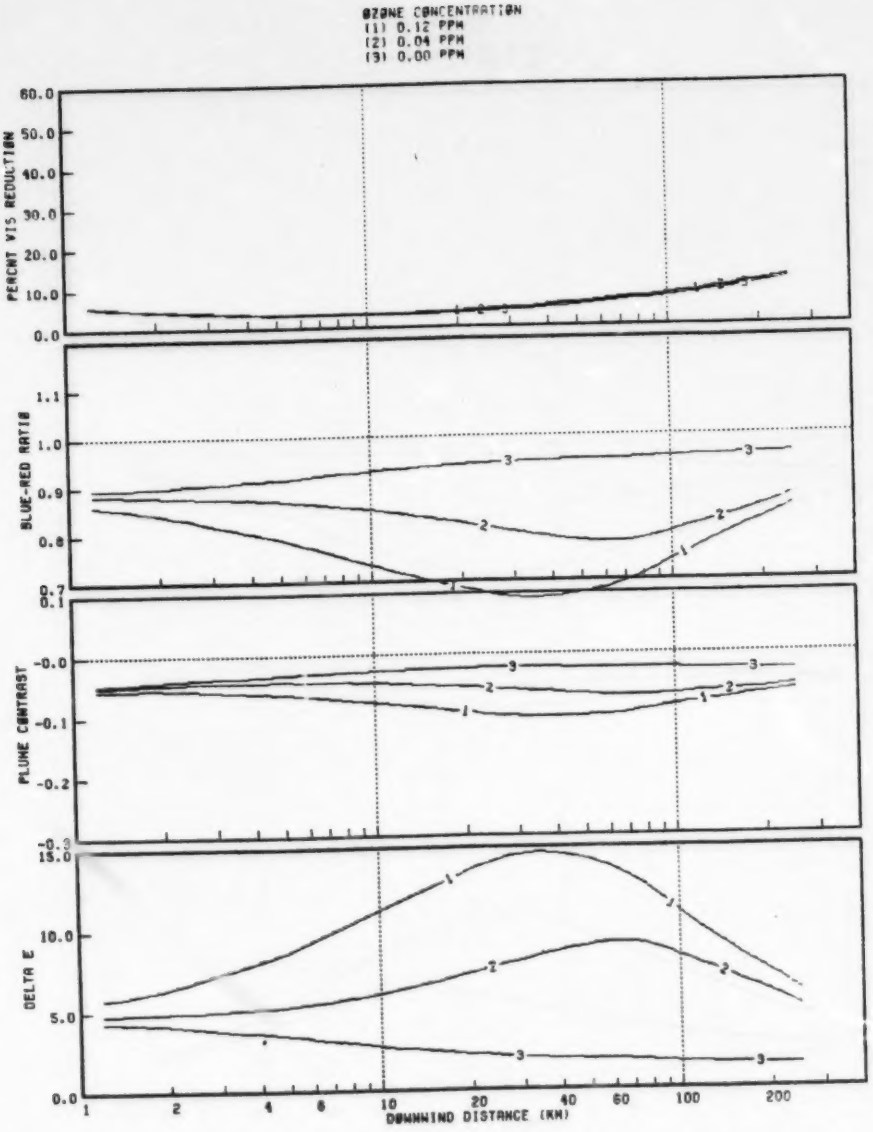
(h) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Eastern Ambient Conditions with Pasquill Stability E

FIGURE 6 (Continued)



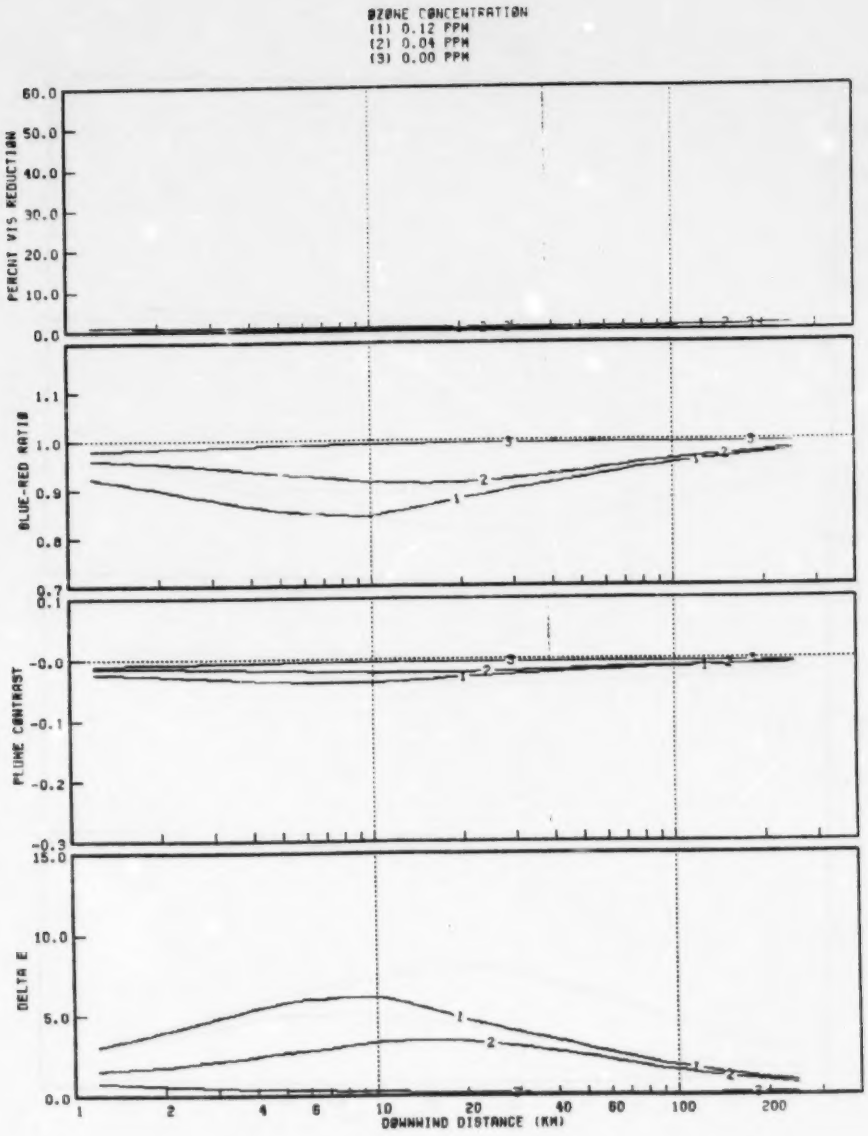
(i) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability D

FIGURE 6 (Continued)



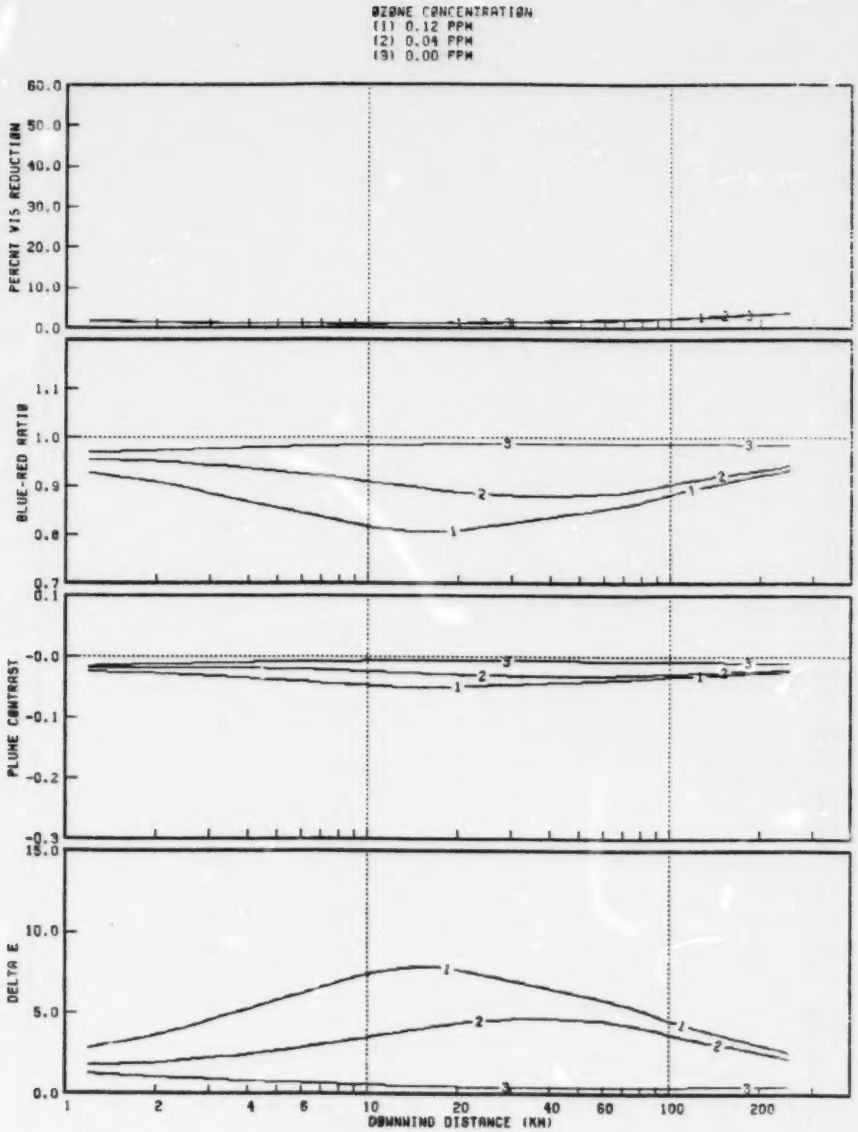
(j) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability E

FIGURE 6 (Continued)



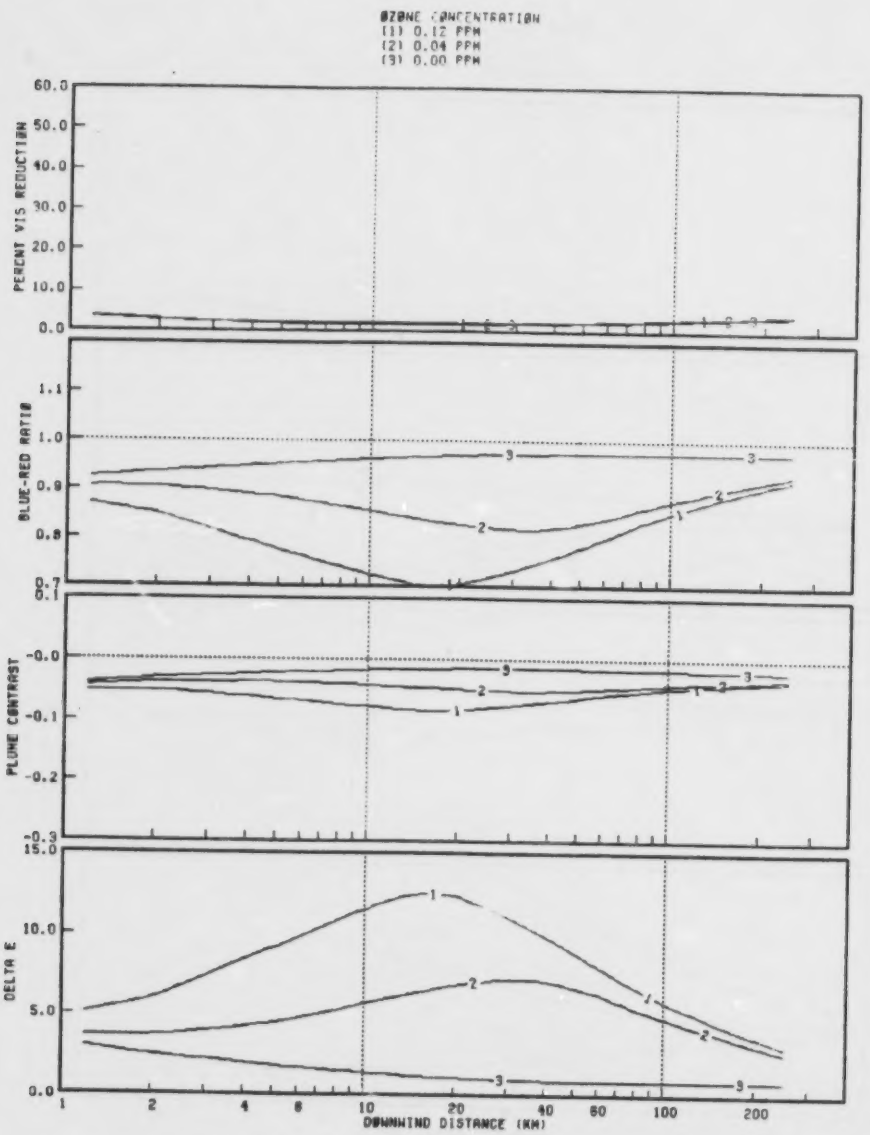
(k) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability D

FIGURE 6 (Continued)



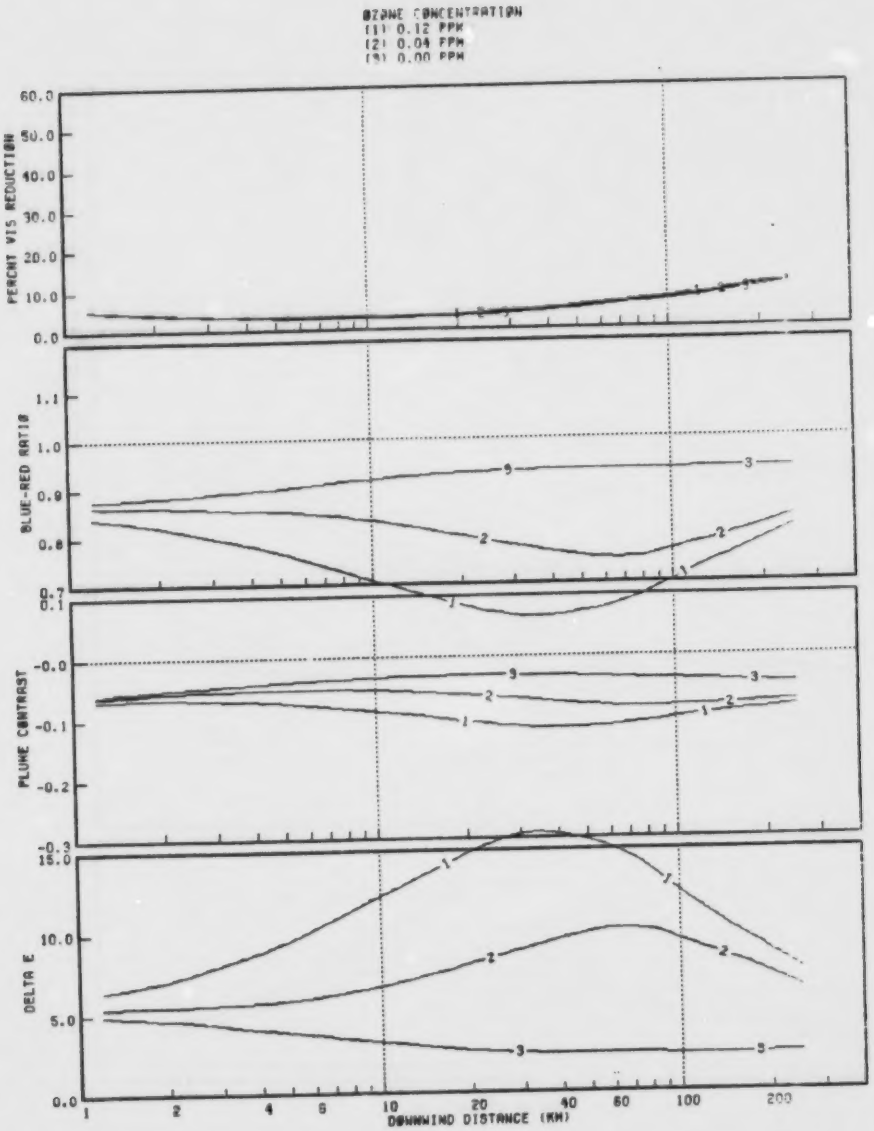
(1) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Western Ambient Conditions with Pasquill Stability E

FIGURE 6 (Continued)



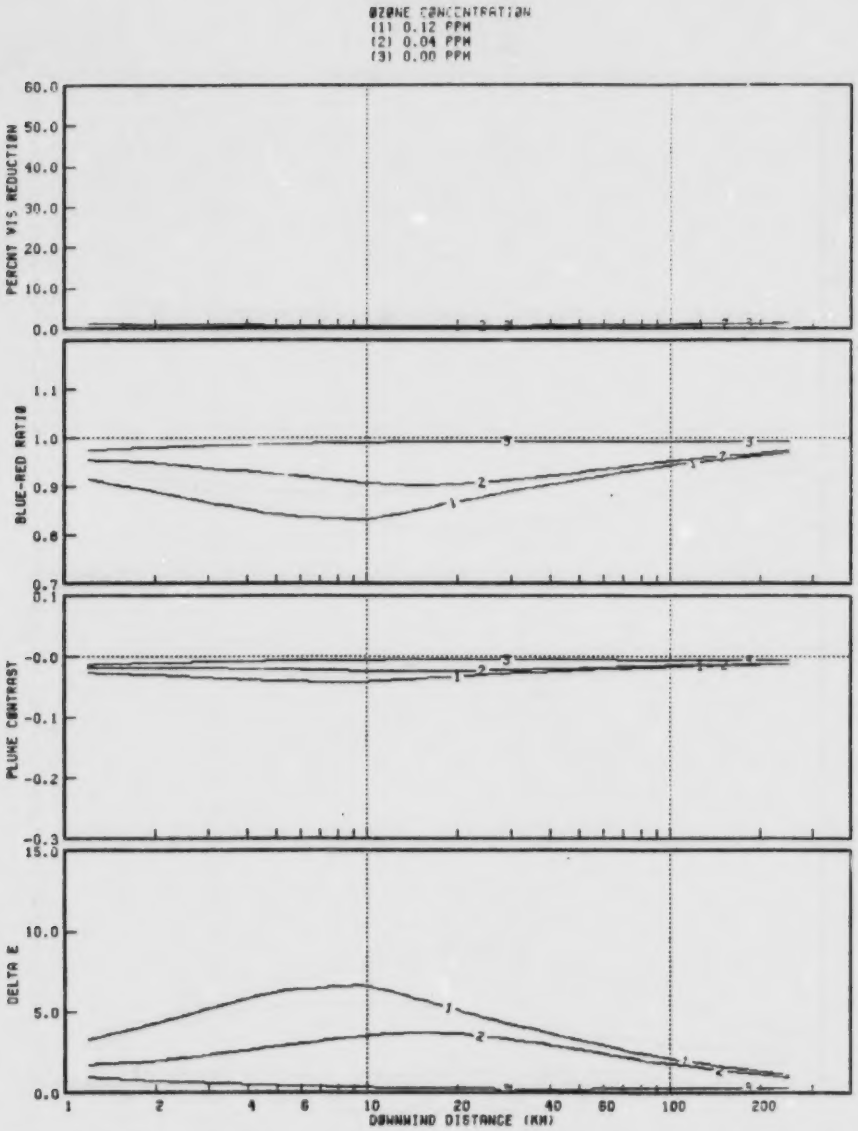
(m) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability D

FIGURE 6 (Continued)



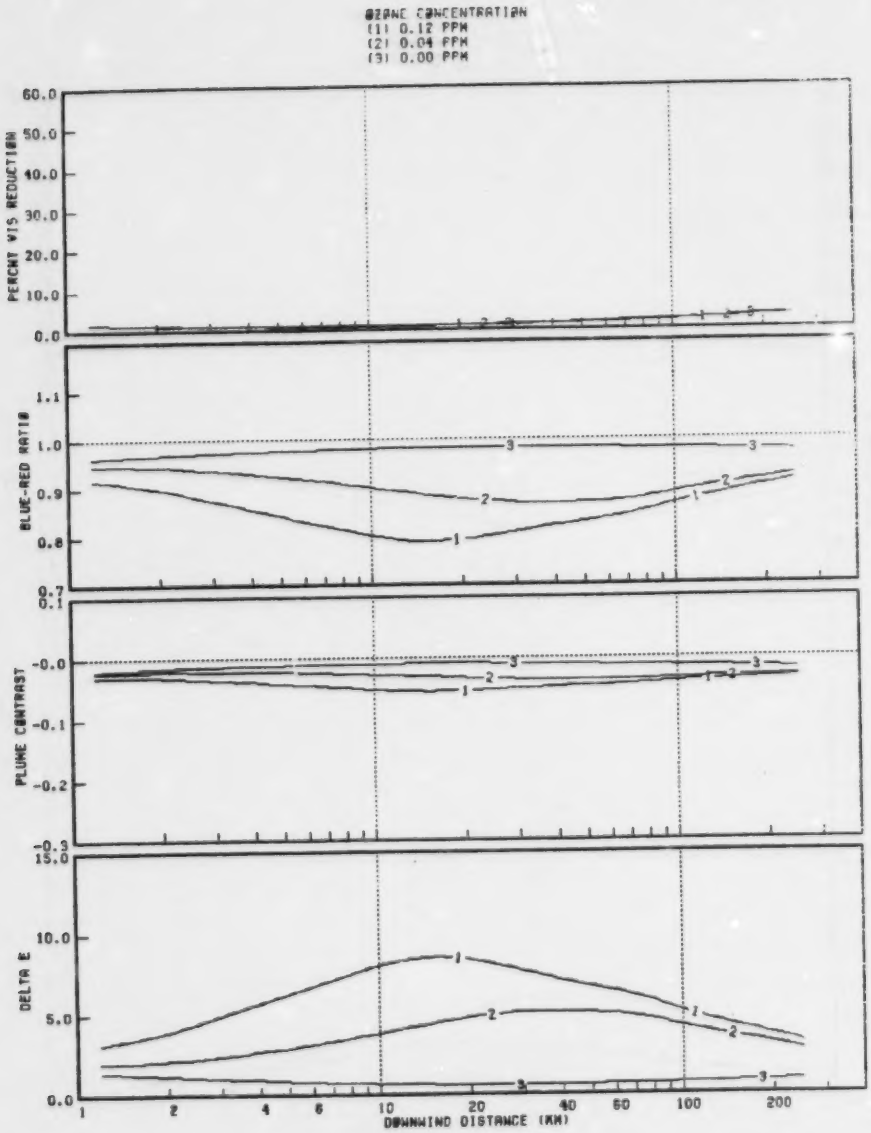
(n) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability E

FIGURE 6 (Continued)



(o) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability D

FIGURE 6 (Continued)



(p) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Western Ambient Conditions with Pasquill Stability E

FIGURE 6 (Concluded)

VIII A SUMMARY OF TYPICAL VISIBILITY IMPAIRMENT CAUSED BY POWER PLANTS IN THE EASTERN AND WESTERN UNITED STATES

We have rearranged the plots shown in different figures to compare on a single plot the visibility impairment caused by power plant plumes under typical eastern and western U.S. ambient conditions, where background visual ranges are poor and excellent, respectively. Figures 7(a) through 7(h) compare eastern and western visibility impacts for the permutations of:

- Atmospheric stability (Pasquill D and E).
- Power plant size (750- and 2250-Mwe).
- Typical and best background visual range.*

These plots indicate that at the assumed 5 km plume-observer distance the discoloration of power plant plumes is not likely to be perceptible in the eastern United States, where a typical background visual range is 15 km (9 miles); but in the nonurban areas of the western United States, where a typical background visual range is 130 km (80 miles), plumes from large power plants are likely to be perceptible as a yellowish (or possibly brown) haze.

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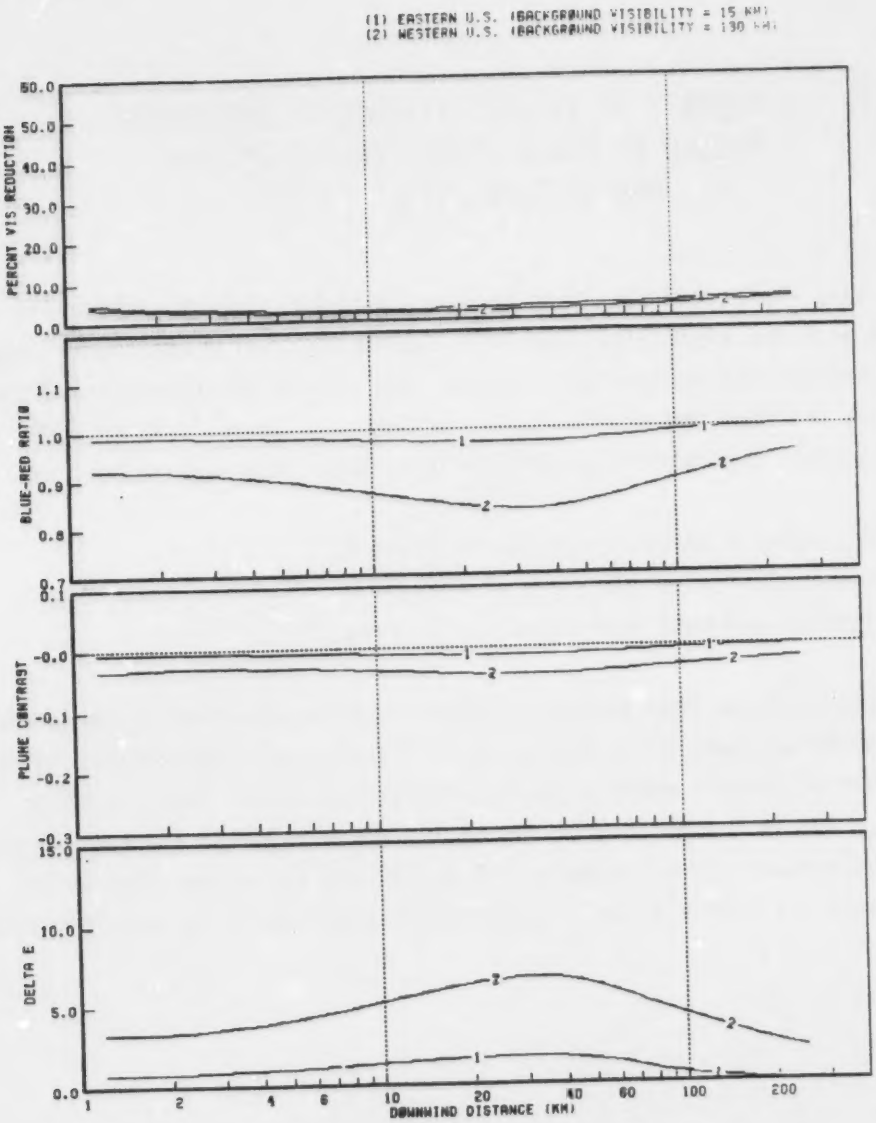
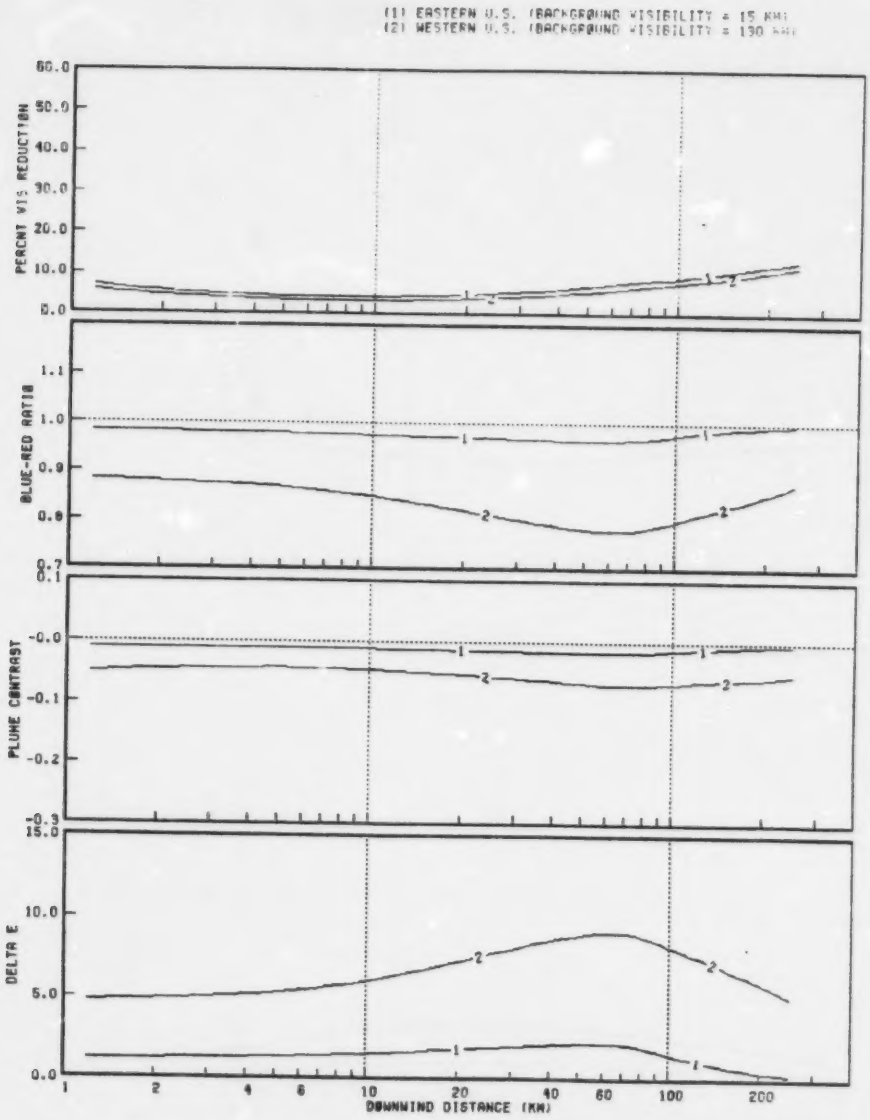
* See key on p. v and Table 1 on p. 5 for base conditions.


(1) EASTERN U.S. (BACKGROUND VISIBILITY = 15 KM)
(2) WESTERN U.S. (BACKGROUND VISIBILITY = 130 KM)
PERCNT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

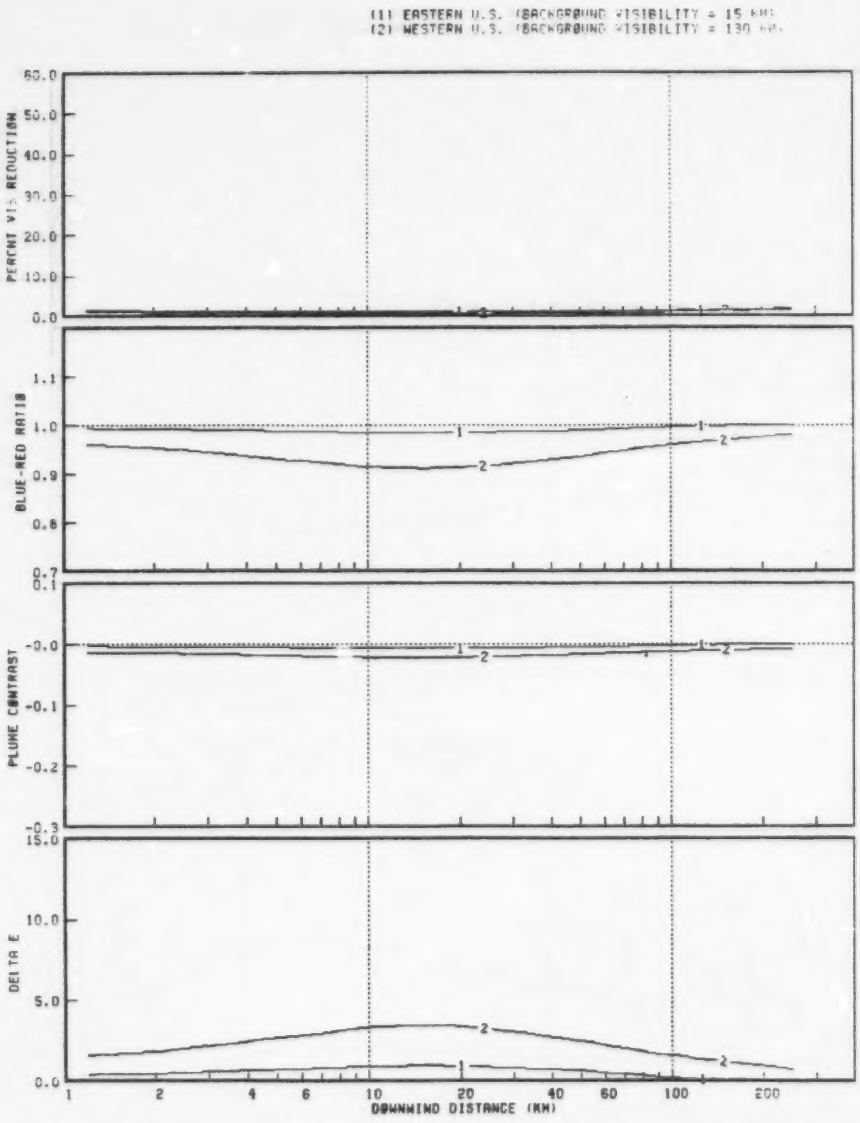
(a) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Visibility with Pasquill Stability D

FIGURE 7. COMPARISON OF PLUME VISIBILITY IN THE EASTERN AND WESTERN UNITED STATES


(1) EASTERN U.S. (BACKGROUND VISIBILITY = 15 KM)
(2) WESTERN U.S. (BACKGROUND VISIBILITY = 130 KM)
PERCNT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

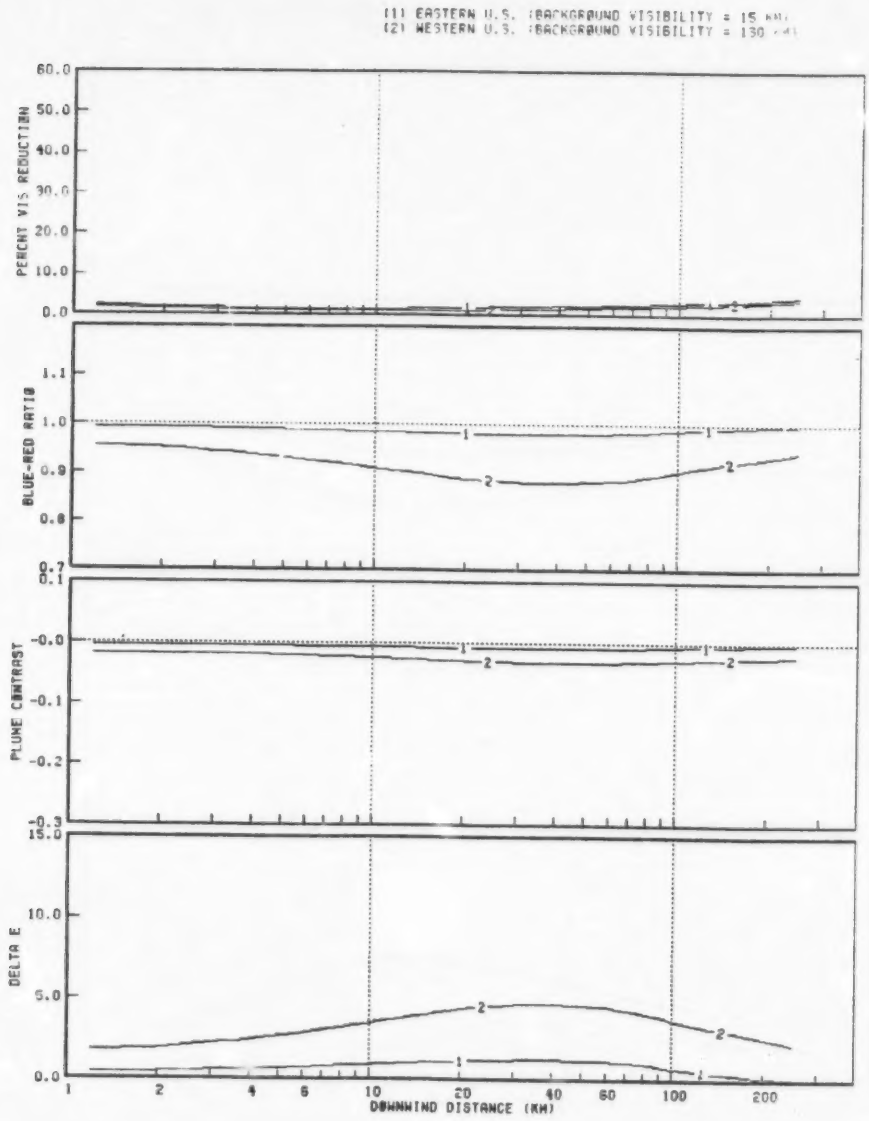
(b) Hypothetical 2250-Mwe Coal-Fired Power Plant; Typical Visibility with Pasquill Stability E

FIGURE 7 (Continued)



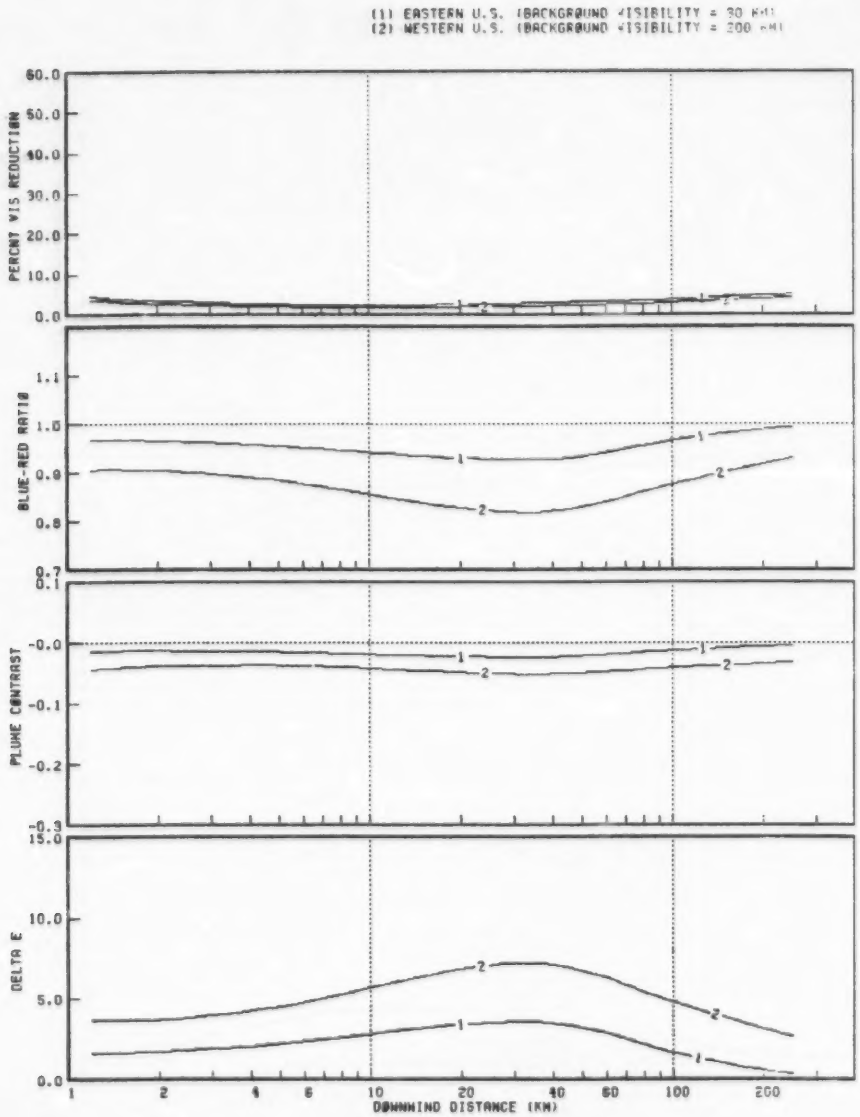
(c) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Visibility with Pasquill Stability D

FIGURE 7 (Continued)



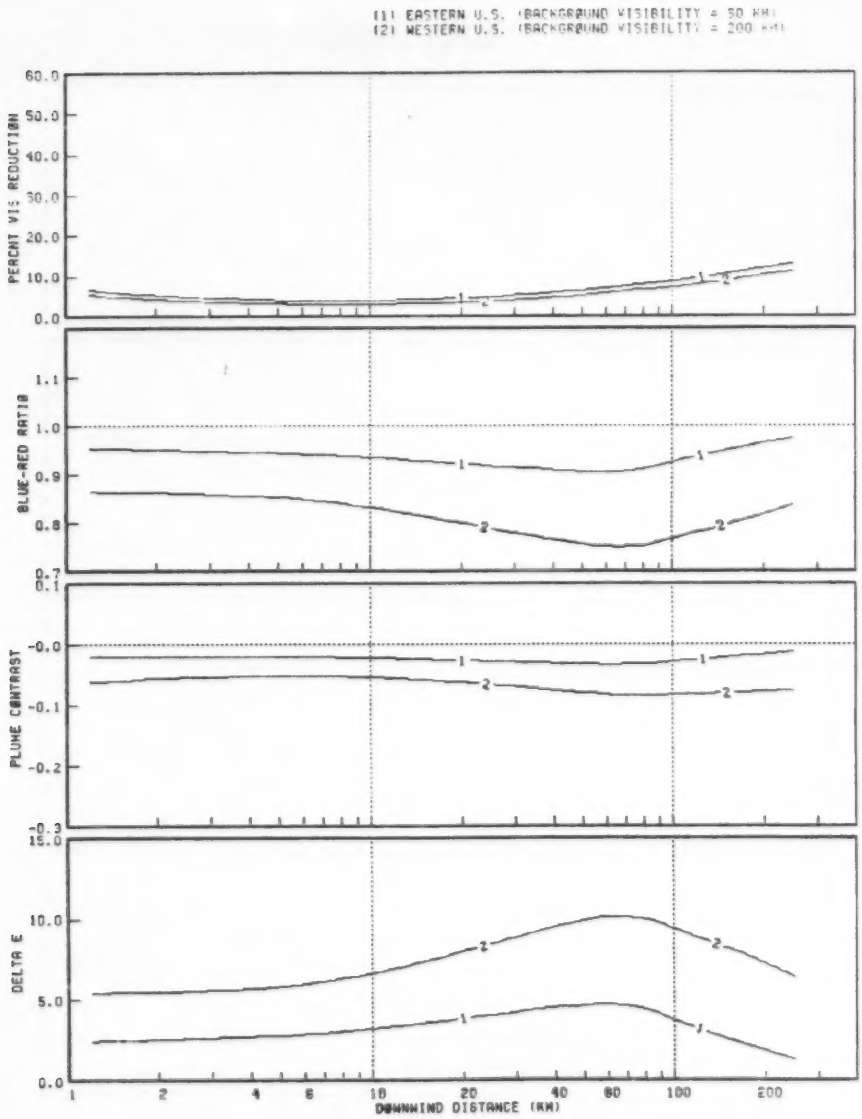
(d) Hypothetical 750-Mwe Coal-Fired Power Plant; Typical Visibility with Pasquill Stability E

FIGURE 7 (Continued)



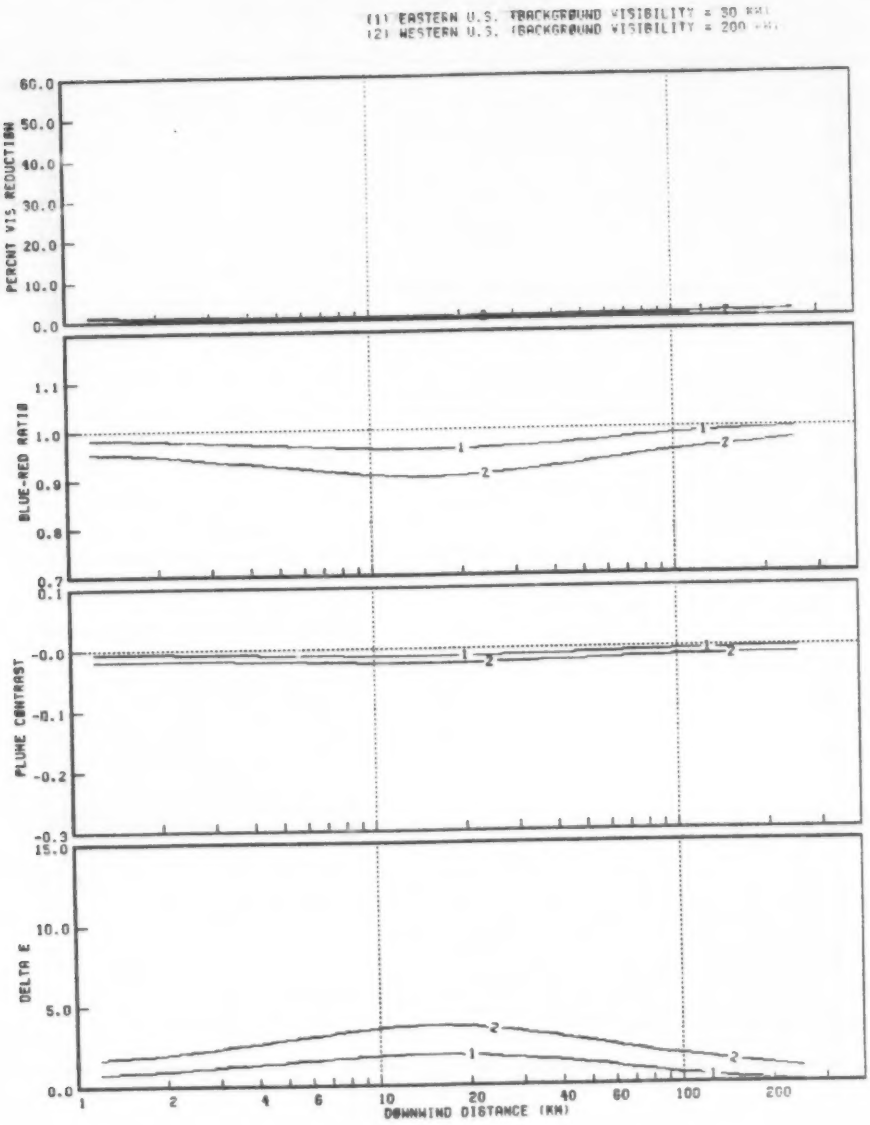
(e) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Visibility with Pasquill Stability D

FIGURE 7 (Continued)



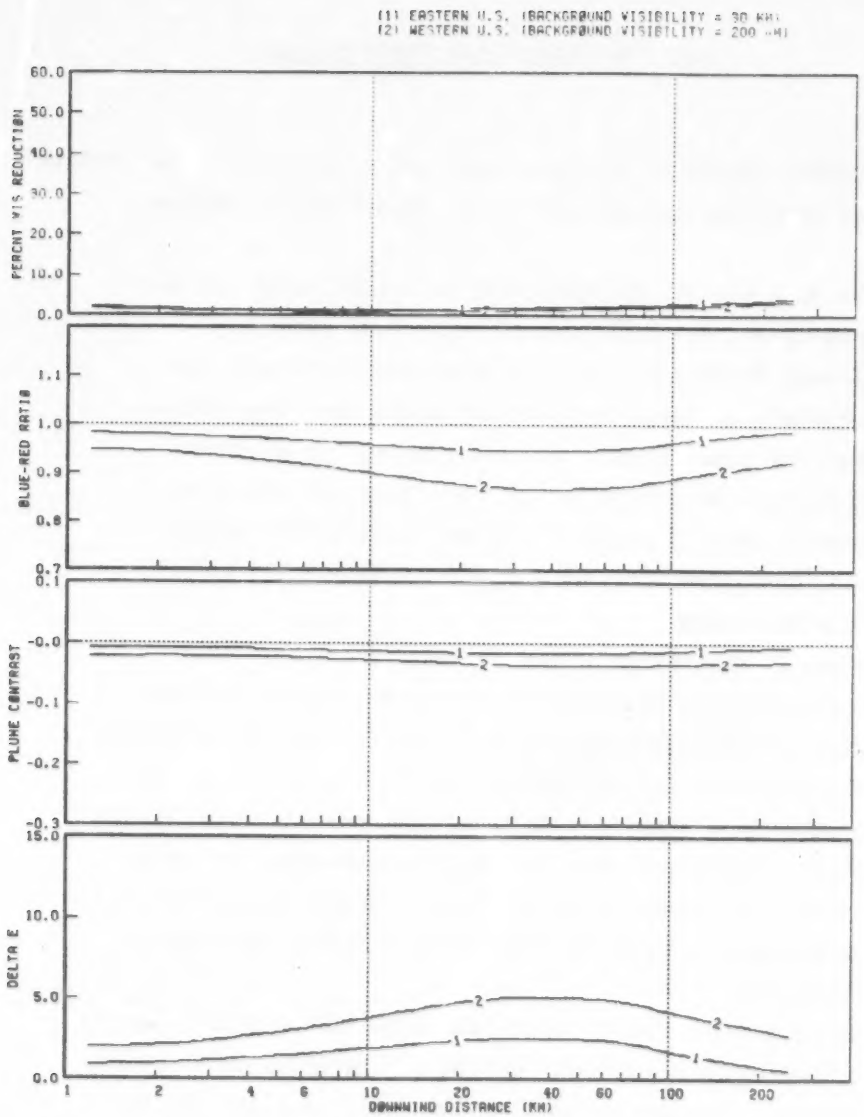
(f) Hypothetical 2250-Mwe Coal-Fired Power Plant; Best Visibility with Pasquill Stability E

FIGURE 7 (Continued)



(g) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Visibility with Pasquill Stability D

FIGURE 7 (Continued)


(1) EASTERN U.S. (BACKGROUND VISIBILITY = 30 KM)
(2) WESTERN U.S. (BACKGROUND VISIBILITY = 200 KM)
PERCNT VIS REDUCTION
BLUE-RED RATIO
PLUME CONTRAST
DELTA E
DOWNWIND DISTANCE (KM)

(h) Hypothetical 750-Mwe Coal-Fired Power Plant; Best Visibility with Pasquill Stability E

FIGURE 7 (Concluded)

IX SUMMARY AND CONCLUSIONS

We briefly summarize the most important conclusions drawn from this analysis of power plant plume visibility impairment as follows:

- The most significant reduction in visual range due to power plant emissions occurs because of secondary aerosol formation (e.g., sulfates and nitrates), particularly at large downwind distances more than 100 km from the power plant. For new plants, fly ash emissions must be controlled so that stack opacity is no greater than 20 percent in order to meet NSPS limits and, therefore, fly ash emissions have a small effect on visual range.
- Plume discoloration (plume blight) is of particular concern and is caused primarily by NO_2 formed by reactions in the atmosphere with O_2 and O_3 from NO_x emissions. Discoloration will be more perceptible under clear background conditions (a good background visual range) during stable conditions with high background ozone concentrations. In certain circumstances, fly ash and sulfate will contribute somewhat to discoloration and plume perceptibility.
- Reductions in visual range caused by 750- and 2250-Mwe coal-fired power plants meeting NSPS will be small (< 10 percent) for average ventilation conditions and SO_2-to-sulfate conversion rates of 0.5 percent/hr.
- Reductions in visual range could be significant (> 25 percent) when conditions are such that sulfate is rapidly formed, during poor plume dispersion conditions (e.g., with light winds, stable air), or if the regional effects due to several sources are considered.

- Atmospheric discoloration caused by 2250-Mwe coal-fired power plants will be perceptible as a white, grey, yellow, or brown haze, particularly in areas with excellent background visibility, and during stable conditions when plume dispersion is poor.
- Plumes from power plants located in the eastern United States are not likely to be perceptible because of the typically low background visual range; in nonurban areas in the western United States, plumes from large coal-fired power plants will be perceptible at times, even as far as 100 km downwind.
- Visibility impairment will be greater than indicated here when plume dilution is poor under stable, light wind conditions, or when plumes are viewed along the plume centerline or obliquely. Also, if emission rates and particle size distributions are different from those assumed here, visibility impairment will be different. More detailed analyses based on appropriate emission, meteorological, and ambient conditions are needed to evaluate fully the visual impact of a given source.
- We suggest that the user of this document exercise caution in applying these results to specific power plant analyses. These results are idealized cases for specific emission, meteorological, ambient background, and viewing conditions based on a model that has not yet been validated.

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